INTELLIGENT COMPUTER-AIDED DISPATCHING FOR URBAN POLICE PATROL UNITS

Joseph Howard Johns

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ABSTRACT

Current computer-aided dispatch (CAD) systems for urban police do not utilize the full potential of the computer and associated peripheral equipment in the processing of calls for police service. This report proposes ways in which CAD systems can be used more efficiently in the dispatching process.

The capabilities of a typical operational computer-aided dispatch system are examined, and problem areas in the dispatching process are identified. Results of a survey of a small group of urban police departments are included which indicate additional problems in the dispatching of patrol units and opinions of police administrators regarding facets of police patrol operations which can benefit from the more complete utilization of computer capabilities.

Several "intelligent" computer-aided dispatch algorithms are presented which improve the dispatching process by taking advantage of the computational, storage, and rapid printing capabilities of computers and peripheral equipment. A specific CAD algorithm termed "adaptive dispatching", a strategy for the stacking of low priority calls for service which uses information concerning the length of the present period of service of each patrol unit, is examined in detail through simulation techniques. This strategy is shown to be an effective means for significantly decreasing the number of intersector dispatches with acceptable increases in average waiting times of calls for police service.

Important factors for ensuring the success of computer-aided dispatch systems are identified, along with policies for the implementation of systems of advanced technology and operational impacts of such systems on departmental procedures and personnel. Areas for further research in CAD technology are outlined.

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CHAPTER I

INTRODUCTION

O.W. Wilson[1] has stated that, "(P)olice have been assigned a disproportionate amount of responsibility for both the present level of crime and the efforts to cope with it in the future." In evaluating the status of police departments with regard to their ability to provide the services demanded by the public, the Institute for Defense Analyses[2] identified the reduction of response times as being crucial to the expansion of services under conditions of fixed resources. Furthermore, it was concluded that "...the best allocation of (budgetary) resources would be in automating the communications center operations by such means as using computers to perform some of the dispatching functions...", and that"...some improvement in crime prevention and clearance could be expected from modifiying the criteria for assigning priority to dispatch orders for from providing better information to the dispatcher."

The first use of a real-time computer system by a police department began in St. Louis in 1964. Since that time, computer applications for police have received considerable support from both local and federal sources. The once extremely rapid installation of computer systems in police departments has, however, slowed in recent years. Colton's 1974 study[3] revealed that police administrators, once anxious for any

technological innovations, are becoming more pragmatic in their approach to computer installations, and now harbor more interest in whether a particular computer application can beneficially influence police operations in a cost-effective manner. Unfortunately the record of computer systems hardware and software in police applications has not been good. Failures have quite often been a result of either the inability of a system to adequately meet the expectations or technical expertise of police administrators, or the lack of acceptance by personnel of new procedures instituted with the technological "advance". Several systems have fallen into disuse due to an absence of in-house technical support. Furthermore, vendors have been known to sell police departments a "bill of goods" in the form of systems which are not consistent with operational needs[4].

Although Colton[5] found that resource allocation, crime statistical files, police patrol and inquiry, and computer-aided dispatch were the four application areas most valued by police administrators, there are less than twenty departments currently maintaining an operational computer-aided dispatch (CAD) system. There are several reasons for the particularly slow installation of dispatch systems. To begin with, even a basic CAD system requires a considerable data base, including a real-time geographic base file of city streets and crime reporting districts. More importantly, computer-aided dispatch necessitates a major commitment to computer technology on behalf of a police department. Substantial hardware purchase, personnel training, and operational restructuring are part and parcel of CAD technology, and conflicts with city data processing departments are inevitable.

It is surprising that with only a few exceptions, those departments with operational computer-aided dispatch systems have software which provides for little more than the cataloguing of incident data. While CAD systems have replaced the typical complaint card and conveyor belt system described by Larson[6], full use of the information available to the system is by no means accomplished.

This paper concerns the utilization of police-available data to develop an "intelligent" computer-aided dispatch system which goes beyond the mere cataloguing of incident information. Problem areas within the dispatching process which remain unsolved by current CAD systems are identified and possible solutions are offered which take advantage of the computational, storage, and rapid printing capabilities of computers and peripheral equipment. A practical engineering approach is taken in order to present CAD routines which are consistent with police operations and administrative goals. A strong emphasis is placed on the organization of police forces in a command and control context, and on the distribution of timely management information to administrators and key personnel in the dispatching process.

In Chapter II, the capabilities of a particular operational CAD system are described. This system is used to define the structure of computer-aided dispatching and its present role in the dispatching process, and to indicate those facets of the command and control system which can benefit from the more efficient utilization of the computer. Chapter III includes the results of a questionnaire sent to a select group of urban police departments considered knowledgeable of current trends in computer applications for police in order to provide a

broader perspective of the capabilities and design of operational CAD systems and to assess the opinions of police officials regarding tactical and strategic issues of police patrol operations which might be influenced by computer technology. A presentation of "intelligent" computer-aided dispatching as a method for addressing those issues and of solving many of the problem areas identified in the dispatching process begins in Chapter IV, followed by a detailed description of one particular dispatch algorithm which makes use of service time statistics in selecting the "best" unit to assign to each call for service. Analysis of this strategy, termed "adaptive dispatching", is conducted through the use of simulation techniques. Finally, policy implications of CAD and CAD-related technology are addressed in Chapter VI.

CHAPTER II

AN OPERATIONAL COMPUTER-AIDED DISPATCH SYSTEM

2.1 Introduction

The dispatching process is that function of the police response system[7] which includes the sequence of actions undertaken by a police department from the receipt of a call for service until the assignment of that job to a patrol unit. This process directly involves three police personnel roles: the complaint operator, who receives the incident information, the dispatcher, who assesses that data and determines which patrol unit to assign to the call, and the patrolman, who can either be on foot or in a vehicle. While most urban police departments continue to perform the tasks of the dispatching process manually, many cities are employing computer technology as a means for improving the efficiency of call handling procedures. It is the purpose of the present chapter to describe a typical computer-aided dispatch system and its role in the dispatching process, and further to indicate areas within the police response system which might be improved by more fully utilizing the capabilities of the computer and its peripheral equipment.

The Huntington Beach Command and Control System described in this chapter incorporates a UHF digital communications capability and a computer-aided dispatch system which has features that are characteristic

of the present "state-of-the-art" in police CAD design. All of the capabilities described are either operational or funded and soon to be available. Although the theoretical CAD technology surpasses the level of this system, no currently operational computer-aided dispatch system significantly exceeds the capabilities of the Huntington Beach system.

2.2 Background Information

Huntington Beach, California has a population of about 150,000, with two-thirds of the city's growth occurring during the 1960's. An estimated ten million people use the public beaches each year. In a period of ten years, Huntington Beach experienced the transition from small coastal town to budding urban center.

It is not surprising under these circumstances that the town's facilities were rapidly outmoded. While additional manpower could be readily obtained, the change in police operations, facilities and capabilities necessitated by the population explosion was too significant to be developed through a gradual evolutionary process. In particular, the police department's command and control system was entirely inadequate to efficiently handle the increased workload. Radio frequency saturation caused considerable delays in response to calls for service, coupled with confusion and loss of patrol officer safety from an inability to communicate effectively with the command center. Mounting workloads created long queues of calls, and telephone operators and dispatchers could not efficiently process the abundance of complaint

cards used in the manual dispatching process system, resulting in disorganization both in the control center and the field.

In order to overcome their problems, Huntington Beach developed a four million dollar program to improve police facilities and service to the public. One quarter of this amount was dedicated to the design and implementation of a computerized Command and Control Center. The final plan encompassed a UHF digital communication system with mobile transmitters and teleprinters, and a computer-aided dispatch system to process incoming calls for service and interface with county, state, and federal criminal information files. Many of the benefits gained from the installed system were due to the digital communications equipment. While few present CAD systems have this capability, it is a logical first step in the design of a total command and control package for urban police forces, as saturated radio networks are a common problem. Furthermore, as discussed later, the full information-gathering and distributing capabilities of a computer-aided dispatch system cannot be employed without such rapid and efficient communications.

2.3 Objectives of the System

The ultimate objective of the new Command and Control System was to reduce criminal activity through increased resource effectiveness. A secondary goal was to assess the feasibility of using advanced computer technology in the police departments of small and medium sized cities, having populations of from 100,000 to 250,000.

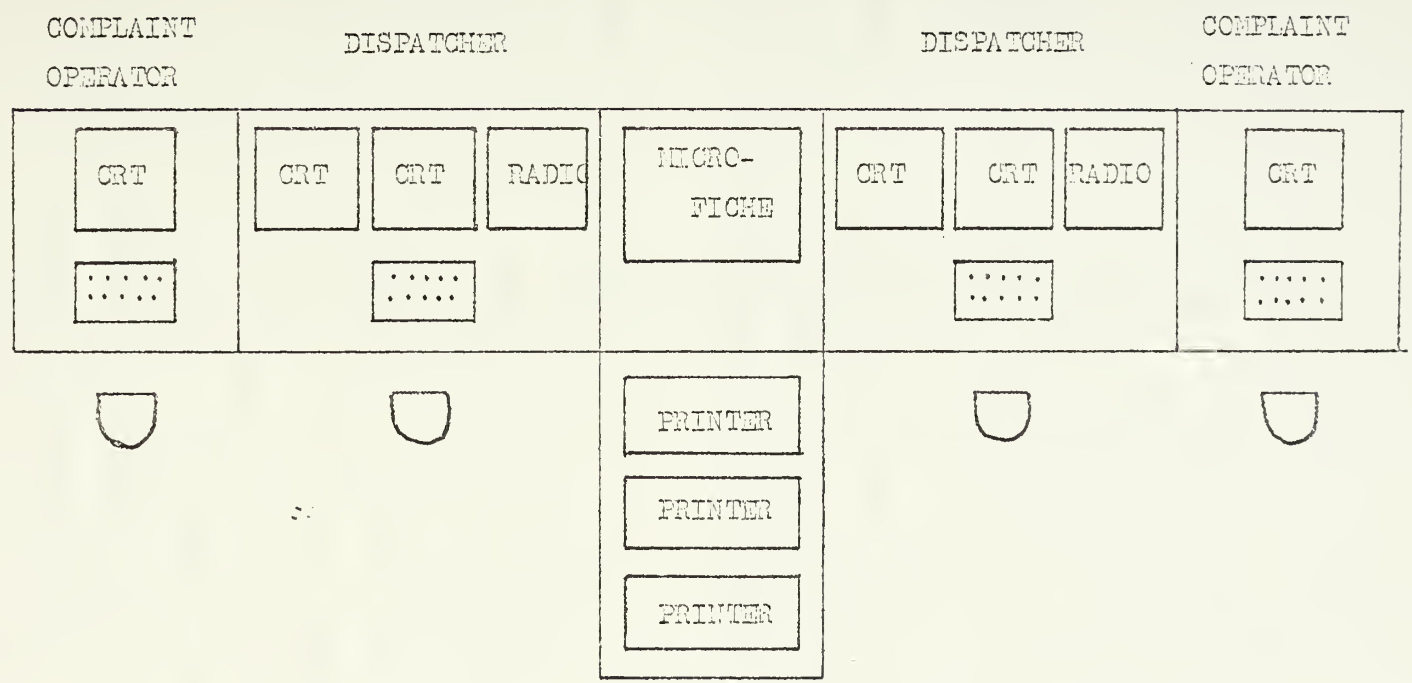
Specific system objectives included improved operational effectiveness through increased communication accuracy, speed, and reliability, reduced response times, higher rates of criminal apprehension, and more rapid and complete dissemination of information; improved officer safety from the improved channels of communication and informational flows concerning hazardous situations; improved community relations through reduced response times to calls for service and increased budgetary efficiency; and a positive influence in the combatting of the accelerating crime rate by decreasing response times and expanding the use of want/warrant files.

The Huntington Beach Police Department identified many of the problems plaguing manual systems of the dispatching process. These included the infeasibility of manual access of files containing data on reporting districts, geographical locations, and police patrol areas, delays experienced in recording incident information on complaint cards, and the failure to effectively transmit criminal data to patrolmen enroute to possible hazardous situations.

2.4 System Components

The Huntington Beach computer-aided dispatch system is based on two mini-computers and associated peripheral equipment, including CRT displays, magnetic tape units, three hard-copy printers, and recorders for taping telephone and radio conversations. The four-position console contains stations for two complaint operators and two dispatchers. Figure 1 depicts the console layout.

FIGURE 1: CONSOLE LAY-OUT



One mini-computer contains algorithms for processing calls for service, monitoring vehicle availabilities, cataloguing personnel assignments, and interfacing with teleprinters and law enforcement files of outside agencies. The second mini is a back-up unit.

Each complaint operator has a CRT display to enter incident data; dispatchers have one CRT unit for handling complaint data, and another for maintaining patrol unit status information. One hard-copy printer keeps a running log of assigned complaint data which replaces the radio log, another printer copies patrol vehicle status changes, and the third records transmissions with outside law enforcement files, composite vehicle availabilities, unassigned complaints, assigned but unresolved complaints, and data from the personnel identification file.

2.5 Processing a Complaint

When the police complaint operator receives a call for service, he enters the incident address onto a fixed CRT display format via keyboard. The computer automatically retrieves from a geographic base file[8] the reporting district, patrol area, and a geographic reference indicating the direction and distance of the call address from the closest major street intersection. The complaint operator then inputs information about the caller and the incident type code and priority. He then passes this information to the dispatcher.

The dispatcher receives incoming complaint data on one CRT display. On the other display he maintains unit status information which is continually updated through mobile digital transmissions and dispatcher

manual input. Comparing the two displays, the dispatcher chooses a patrol unit to assign to the call and transmits the necessary data to that vehicle either via teleprinter or voice radio. The patrol unit then acknowledges receipt of the assignment via voice radio.

When the assigned unit completes service on the call, the updated complaint data is logged out of the CAD system and printed in hard copy. Figure 2 depicts a flow graph of the CAD call handling process.

2.6 Capabilities

The computer-aided dispatch system contains algorithms to create the following displays and files:

i) Unassigned incidents in queue by priority class or patrol area of origin (a maximum of sixty-four calls)

ii) Calls which are assigned, but not resolved

iii) Personnel duties, shifts, and days off

iv) Want/Warrant data

v) Police hazard information such as gun registrations, criminal histories, and vehicular impediments

vi) Silent Alarm file containing address data and cataloguing number for microfiche files of floor plans, escape routes, safe locations, etc.

Besides the above files and displays, the computer-aided dispatch system is upwardly compatible to allow the introduction of automatic vehicle location[9] and more personnel stations.

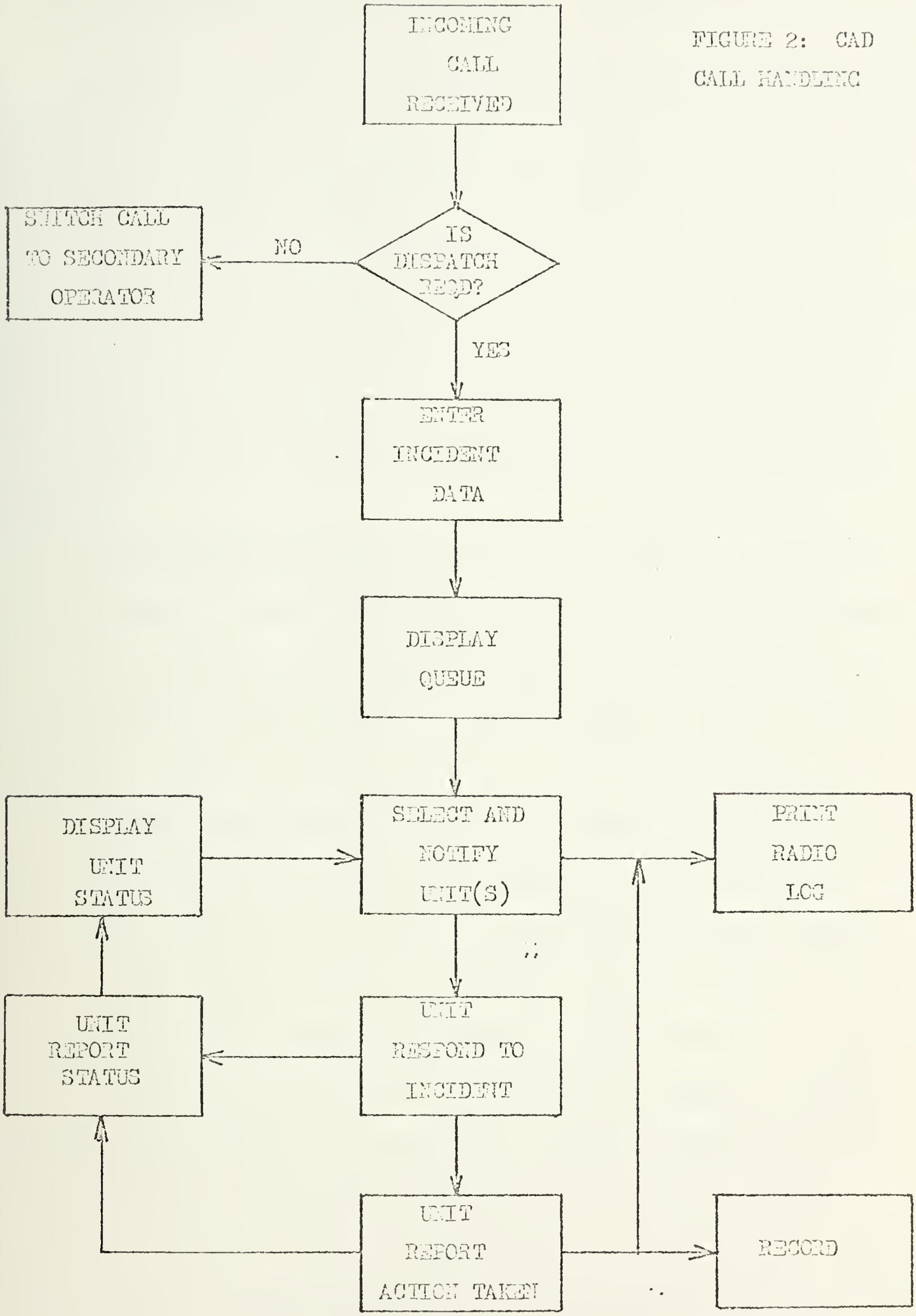


FIGURE 2: CAD CALL HANDLING

2.7 System Evaluation

The Huntington Beach Command and Control System, like all other presently implemented systems, does not utilize the full technological capabilities available today. In particular, the storage and computational capabilities of the computer are employed only for cataloguing incident data and maintaining a minimal number of files containing information useful to the personnel involved in the dispatching process. Furthermore, the high-speed printing capability of the system is not used to produce reports which are of substantial value to police administrators.

It is interesting to examine the true operational cost savings which are available with systems such as that described in this chapter. The City of Huntington Beach reported[10] that an estimated $29,000 are saved annually as a direct result of the CAD system and mobile digital capabilities. Table 1 summarizes the data collected.[11] Note that the only significant savings resulted from the automatic printing of the radio log (625 man hours annually) and from the capabilities of the mobile digital transmission system (a total of 2135 man hours yearly). All of the other listed savings are trivial, as the respective functions occur regularly, but in small time increments. The overall effect of these time savings is to reduce the workload of the complaint operator, dispatcher, and patrolman, but not enough to allow a reduction in manpower. Furthermore, none of the stated benefits has a significant impact on the response times to calls for service. Hence, the savings listed in Table 1 are <u>not realized</u>, particularly if one were to consider

TABLE 1: ESTIMATED TIME SAVINGS OF THE

HUNTINGTON BEACH COMMAND AND CONTROL SYSTEM

FUNCTION	TIME CONSUMED (SECONDS)		MAN-HOURS SAVED[T1]
	MANUAL SYSTEM	COMPUTERIZED SYSTEM	
Write complaint data	No change observed		0
Transfer complaint to dispatcher	6.0	0.0	76.6
Review and sort calls	6.0	2.0	51.1
Dispatch unit/receive acknowledgment	38.0	38.0[T2]	431.5
Record response time	18.0	0.0	229.2
Enter file number	4.0	0.0	51.1
Type radio log	60.0	11.0	625.5
Change status display	4.2	9.9[T3]	282.9
Record status by time	7.7	0.0	359.7
Report field status	5.5	0.8	429.6
Complete unit dispatch log	50.0	7.0	1306.2
	Total man-hours saved		3843.3
	Equivalent dollar value		$29,073.02

Notes:

T1. Based on the 1973 level of calls for service.

T2. The new system requires voice communication with motorcycles and for priority one calls. These encompass 11.02% of all calls.

T3. This function required for motorcycles only (11% of total changes).

amortization and upkeep of the CAD system equipment, or the possible need to hire an in-house technical staff to support the system.

Qualitative benefits of the Huntington Beach Command and Control System are hard to identify and evaluate. Certainly morale is enhanced due to reduced workloads and a new working environment, and officer safety is improved through the availability of hazardous address and want/warrant data and the 90% reduction in voice radio utilization due to mobile digital capabilities. While such qualitative benefits are of course important to consider when implementing any systems of advanced technology, the effects normally are not readily apparent for some time after system installation, and monetary values can rarely be assigned.

2.8 Summary

The Huntington Beach Command and Control System has been presented as having a computer-aided dispatch capability characteristic of other currently implemented systems. While the system's mobile digital communications ability produces considerable savings in air-time, the potential of the dispatch system as a whole is greatly under-utilized. Man-hour reductions experienced are not realized as lower operating costs, since time savings accrue in small increments, with no resultant decrease in manpower.

Chapter IV discusses ways in which the CAD system can be used to improve the dispatch decision process, resulting in the more rational utilization of police resources. It is this latter capability of computer-aided dispatching that produces effects which, though difficult

to measure, are nevertheless considerably more significant than the small man-hour savings typical of present CAD systems.

CHAPTER III

SURVEY

3.1 Introduction

While the Huntington Beach Command and Control System provides an example of a typical computer-aided dispatch system, it would be helpful to develop a broader perspective of the capabilities and design of operational CAD systems. More importantly, it is necessary to determine the opinions of police administrators regarding facets of police patrol operations which can benefit from the more complete utilization of computer capabilities. This information will provide a framework from which to develop an "intelligent" computer-aided dispatch system that is consistent with police operating procedures and administrative goals.

In order to determine the above, a survey was conducted of a small group of urban police departments considered knowledgeable of current trends in computer applications for police. Nineteen of the twenty departments chosen responded. Of these, fifteen had some type of computer-aided dispatching, or were sufficiently into the stages of design and financing that they were considered in the group which had operational CAD systems; two cities had only just begun to think in terms of CAD; one was involved in the early stages of a large, complex, integrated system; and the last had an automatic vehicle monitoring (AVM)

system, but no other computer-aided dispatch capabilities. References make in this chapter to CAD system structure assume all fifteen of the first group above have operational systems. This assumption has the effect of inflating some of the figures given later, but is is felt that this procedure will give a better understanding of present CAD system design patterns. A copy of the questionnaire used can be found in Appendix 1. Statistics collected are summarized in Figure 3.

3.2 Dispatch Algorithms

Fifteen police departments of the sample group of nineteen utilize a dispatching decision structure which approximates what can be considered a "standard" dispatch algorithm. The standard dispatch assignment is:

i) If free, dispatch unit assigned to the patrol sector about the incident address

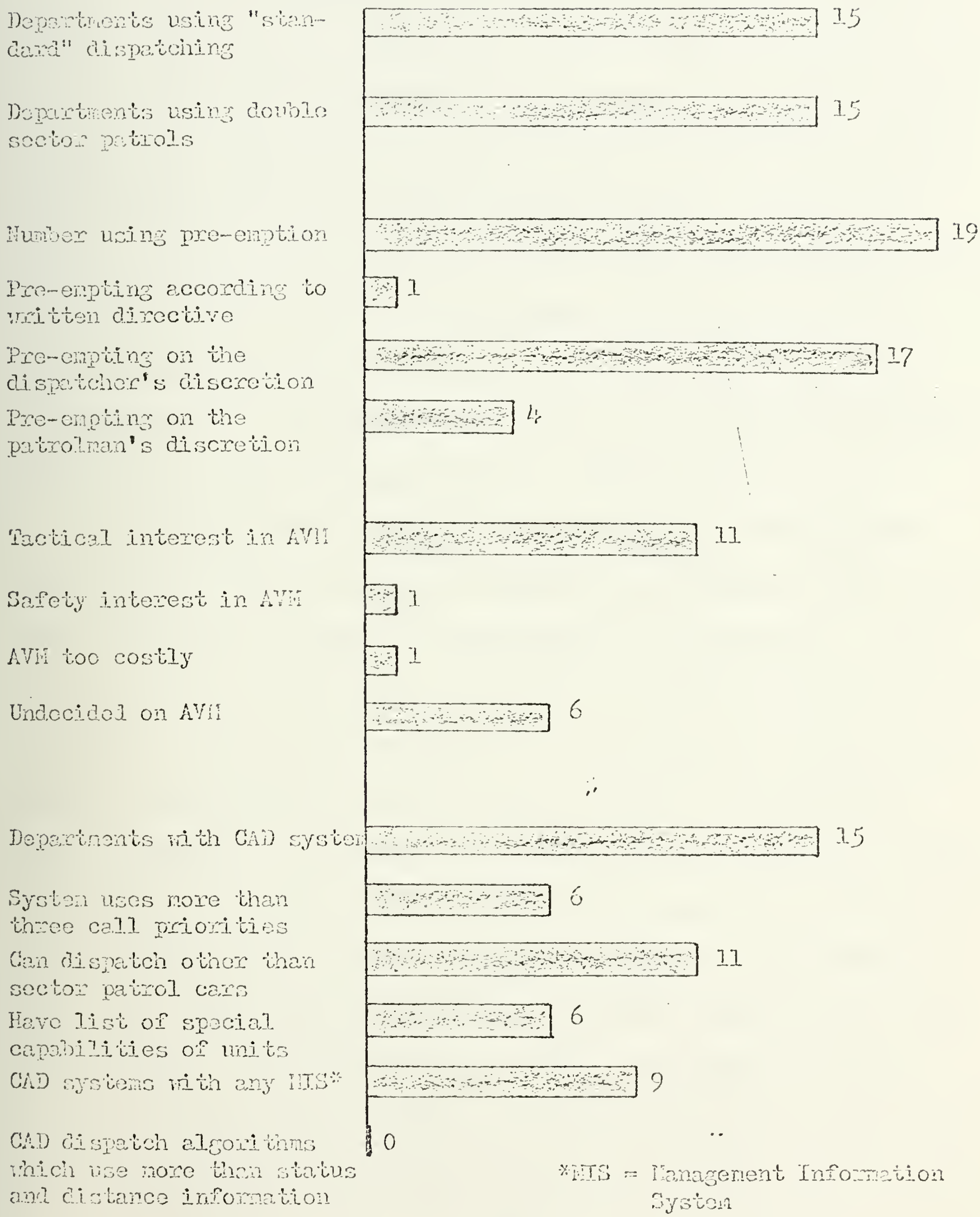
ii) If busy, dispatch "closest" free unit

iii) If all units are busy, queue the call, using a first-come, first-served by priority strategy as units become available

The determination of the "closest" unit is crucial to the process, as incorrect choices result in increased response times to incidents. Larson[12] observed that most dispatchers use a "strict-center-of-mass" strategy, estimating both the unit and incident address locations to be at the statistical centers of their individual sectors. Some

FIGURE 3: SURVEY STATISTICS

Results obtained from a sample of nineteen urban police departments.

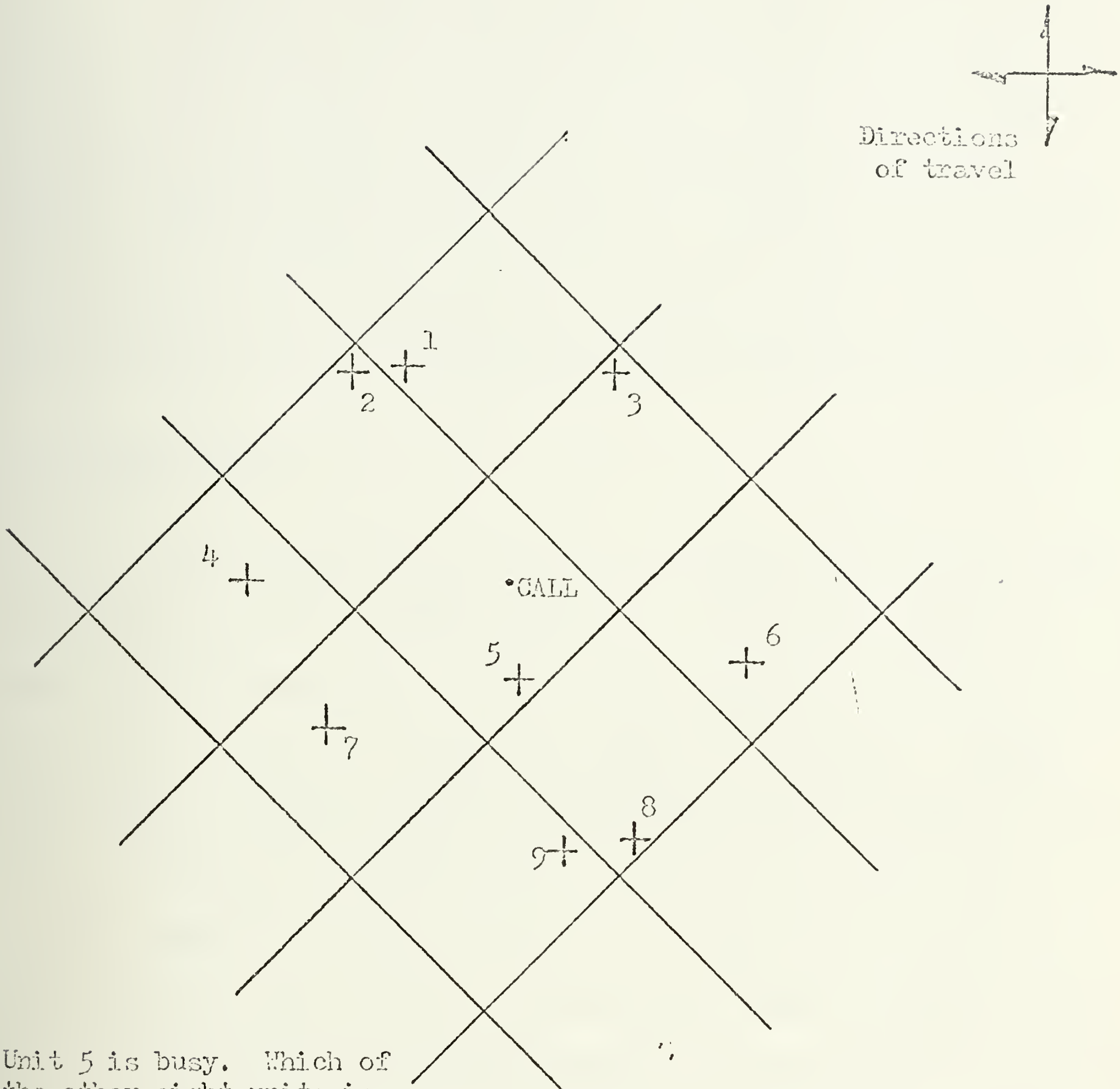


dispatchers improve on this policy by using a "modified-center-of-mass" strategy, wherein the unit is assumed to be at its sector center, but the exact location of the incident requiring a patrol unit is considered. In either case, selecting the "closest" unit is difficult, as can be seen in Figure 4.

Two of the four police departments not using a "standard" dispatch indicated that they stacked low priority calls for service at a later time when the sector-assigned unit became available. Two also considered, in some rough manner, the length of time a call had been waiting for service. For example, if a low priority call had been stacked in queue a long time while awaiting its sector unit, another unit would be considered for dispatch into that sector. These dispatch algorithms, therefore, are quite different from the standard strategy.

It is interesting to note that the standard dispatch algorithm described above does not encompass several considerations in which urban police departments, including those surveyed, are interested. A significant percentage of the fifteen departments using the standard dispatch algorithm also indicated an interest in the maintenance of neighborhood identity, whereby each patrol unit remains inside his own sector as much as possible. All nineteen respondents use some form of pre-emptive dispatching, which allows for the removal of a unit from the service of a low priority call, in order to assign that unit to a high priority call when no other free units are in a reasonable vicinity of the high priority call. The nature of police-citizen interaction indicates an obvious need for stringent regulations regarding the use of pre-emptive dispatching. However, only one department of the sample group maintains

FIGURE 4: SELECTING THE CLOSEST UNIT



Unit 5 is busy. Which of the other eight units is closest to the call?

By "strict-center-of-mass" : All are equally "close".

By "modified-center-of-mass" : Unit 3 is "closest".

Exact location-to-location: Unit 4 is closest.

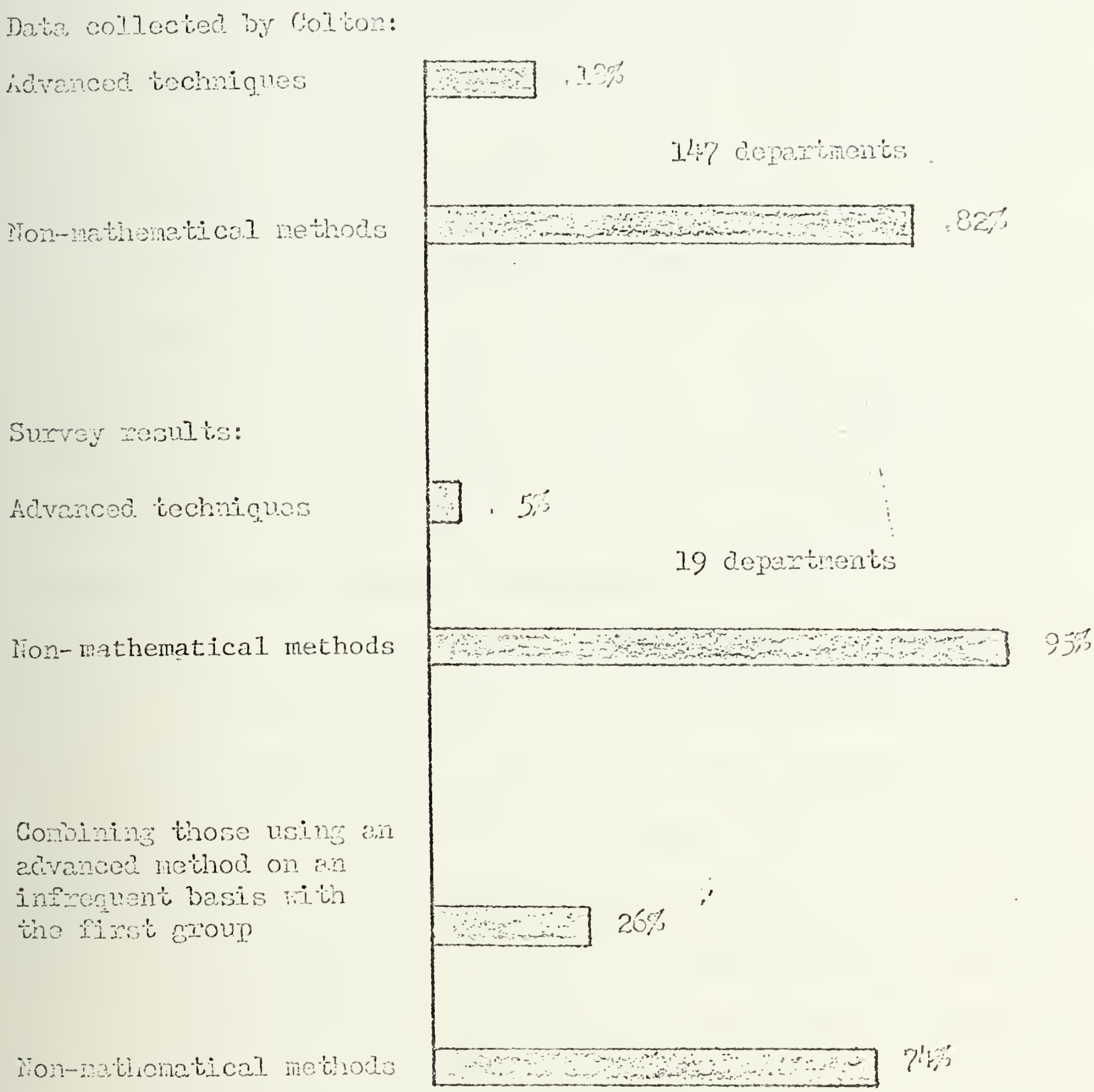
a written directive on pre-emption! Seventeen departments authorize the dispatcher (or his immediate supervisor) to exercise discretion in pre-emptive dispatch situations; five considered the patrolman's opinion as to whether or not his present client should have service pre-empted. This author's observations of one of the departments sampled would indicate that, in actuality, the patrolman and dispatcher co-operate in the decision process more than some police administrators might realize, and in a way beneficial to the client and the department.

3.3 Sector Design

The foundation of any manual or computer-aided dispatch system is the manner in which patrol resources are allocated throughout the police jurisdictional area. Of particular importance is the method in which patrol sectors for radio-motor vehicles are designed. Current philosophies on optimal sector geometry concern the balancing of patrol unit workloads and the minimization of travel times to calls for service.[13] Colton[14] found that only 18% of 147 major urban police departments allocate their resources using some near optimal decision process. Of the nineteen respondents to this survey, only one used such a resource allocation methodology. Four others used similar strategies, but updated sector design on a longer than annual basis, which this author considers unrealistic in terms of rapidly changing urban environments. Figure 5 compares these results with Colton's.

Adding to the lack of correspondence between present police patrol sector designs and desires to minimize response time and balance unit

FIGURE 5: METHODS OF RESOURCE ALLOCATION



workloads is the fact that rarely are all patrol units in a city manned at any one time. Temporary decreases in manpower are caused by vacations, illness, court appearance, vehicle maintenance periods, and similar circumstances. Fifteen police departments in this sample attempt to provide patrol coverage of the affected sectors during periods of reduced manpower by assigning a neighboring unit to patrol two areas. Clearly, this "double sector patrol" strategy causes unbalanced workloads and increased travel times.

The four remaining departments used policies more in line with concerns to minimize response times and maintain fairly balanced workloads. One had its supervisors concentrate their patrol in the affected sector. Unfortunately, supervisors have other duties,[15] and can not be expected to provide the same level of service to the area as the regular patrol unit does. Another city attempts to operate a fixed number of police patrol vehicles at all times by utilizing foot patrolmen when needed. Of course, this is the "best" operational method of coping with fluctuating manpower if one subscribes to the contention that patrol vehicles are better than foot beat patrols. The last two departments altered sector boundaries so that <u>each</u> of the patrol units in the district had one larger beat. This last strategy for allocating a varying level of patrol resources is examined in more detail in Chapter IV.

3.4 Automatic Vehicle Monitoring (AVM) Systems

Automatic Vehicle Monitoring (AVM) Systems determine the position of each patrol unit, and relay that information to the Command

and Control Center. AVM systems used for police are based upon radio propagation time, proximity detection, dead reckoning, or triangulation techniques.[16] The ability of an AVM system to pinpoint the position of each patrol unit provides the dispatcher with information that allows the selection of the unit which is closest to an incident, even though it might be assigned to an adjacent patrol area. Reduced response times to calls for service can therefore be realized. Other advantages of these systems, not necessarily less important, are the ability to enhance officer safety and the capability for surveillance of the movements of patrol units by police administrators.

While an insignificant number of police departments have an operational automatic vehicle monitoring system, it is interesting to note how administrators view the capabilities of this new police technology. Thirteen departments offerred opinions on the important features of AVM. Only one respondent felt that increased officer safety was the most valuable capability of a system which could accurately determine the location of patrol vehicles. Eleven departments pointed to the tactical issue of reduced response time to calls for service through the ability to accurately determine the closest unit. One department felt that the cost of an AVM system out-weighed all of its benefits.

3.5 Computer-aided Dispatch Capabilities

Of the fifteen police department respondents which either had an operational computer-aided dispatch system, or one in the final stages of design, six took advantage of the computer's ability to easily sort

data by partitioning incoming calls into more than three priorities. As will be discussed in Chapter V, significant advantages can be gained by the use of several priorities for cataloguing calls for service.

While eleven systems allowed the dispatch of units other than patrol vehicles, such as foot patrolman and Traffic Division units, none include patrol unit data in the geographic base file for other than regular sector vehicles. In other words, a call for service can be cleared from the system through dispatch to any unit, but only regular patrol vehicles are recommended for dispatch by any system. Furthermore, several of the CAD systems now operational do not assess the utility of dispatching other than the unit assigned to the sector of call origin, but simply maintain a listing of the status of all patrol vehicles, leaving the decision process <u>entirely</u> to the dispatcher.

Six CAD systems maintain a catalog of patrol unit special capabilities such as advanced medical training, medical equipment and weapons carried, or bilingual speech and sex of police officers. No manual systems had a similar capability. Furthermore, no system utilized this information within the computer's dispatch algorithm.

Finally, nine of the fifteen computer-aided dispatch systems had the capability to produce some form of timely statistical reports for management information. A few designs allowed for the collection and storage of police system statistics on magnetic tape. This policy will allow the easy transition to more sophisticated system designs in the future. A few respondents implied that operational and jurisdictional problems existed between the city's Police and Data Processing Departments. This is considered in Chapter VI.

3.6 Summary

It should be clear from the results of this survey that police administrators continue to experience difficulties in utilizing cost effective, advanced technology within their departments. A concern for the installation of CAD systems hardware prevails over the design of software which makes the system expense more worthwhile, and the co-ordination of different systems is sometimes lacking.

The strongest inconsistency in police operations discovered is the failure of command and control operations, whether manual or computerized, to provide for the agreement of dispatch decision making between dispatchers and departmental policies. This discrepancy is most evident in the inability of the standard dispatch algorithm to account for pre-emptive dispatching and the desire of police administrators to develop and maintain some sort of neighborhood identity with particular patrol units.

The allocation of patrol resources deserves increased attention by police administrators. Policies need to be developed for the deployment of patrol units under conditions of both full and partial manpower that are consistent with departmental goals concerning minimizing response times, the balancing of workloads, maintaining neighborhood identity, and similar issues.

The integration of advanced technology such as automatic vehicle monitoring systems in command and control environments needs to be studied closely to ensure consistency between departmental operating policies and system designs. This survey, for instance, indicates that

tactical considerations are most important in evaluating the cost effectiveness of AVM systems.

The survey also reinforced several of the conclusions drawn from the Huntington Beach Command and Control System. Most significant are the failure of computer-aided dispatch systems to incorporate departmental policies into a decision process for the assignment of patrol units to calls for service, and the minimal use of valuable police-available data such as patrol unit capabilities and statistics useful to police managers. The information gained from this survey will provide a valuable source from which to draw examples of more "intelligent" computer-aided dispatching.

CHAPTER IV

THE POTENTIAL VALUE OF COMPUTER-AIDED DISPATCH SYSTEMS

4.1 Introduction

The previous two chapters have outlined the current state-of-the-art of computer-aided dispatch systems, and have indicated problem areas and issues of importance to police administrators within the dispatching process. It has been stated that many of these problems can be alleviated through the more efficient utilization of the computational, storage, and rapid printing capabilities of the computer hardware of CAD systems.

This chapter contains a discussion of numerous possible solutions to the above problems through the use of "intelligent" computer-aided dispatching. Intelligent computer-aided dispatching involves the more complete utilization of data available to the police department in an effort to provide better service to the public, to use CAD hardware more effectively, and to routinize the dispatching process. Intelligent CAD routines encompass not only complex mathematical algorithms and sophisticated uses of data, but practical operational considerations as well. The possibilities for intelligent CAD technology are varied and limited not so much by budgetary considerations as by the imagination and dedication of police administrators.

The following sections cite specific, major problems in the dispatching process experienced by complaint operators, dispatchers, patrolmen, and administrators, and present intelligent CAD system approaches for their solutions. All of the suggested routines can be implemented with current CAD system hardware; some are at least partially operational in present CAD systems. The discussion that follows assumes that digital communications equipment is a necessary pre-requisite for intelligent computer-aided dispatching. As stated earlier, this is a reasonable requirement in light of the typical high utilization of police radio channels.

4.2 Assisting the Complaint Operator

The primary duties of the police telephone operator are to receive calls for service, assess whether each call requires police response, and if so, obtain the necessary information from the caller. Little attention has been paid in current CAD system designs to the reduction of the considerable time taken by complaint operators to process incoming calls for service. The operator either lacks the proper tools for assessing the validity of calls and verifying addresses of incidents, or must perform a time-consuming search through files for information such as the patrol sector of origin of a call, or the actual street address of locations known to the caller only by a commonplace name such as Kendall Square. The complaint operator also has sole responsibility for assigning a priority to each call for service, unaided by information such as the recent calls from the same area, and the fact

that a call might be a repeat of a previously reported incident. Furthermore, the operator has no way of adequately estimating the expected wait in queue that a caller might experience prior to receiving service, and hence cannot relay that information to the caller. The following section outlines some solutions to the above specific problems which are possible through "intelligent" computer-aided dispatching.

4.2.1 Possible Solutions to Complaint Operator Problems

As stated previously, a geographic base file (GBF) is a prerequisite for computer-aided dispatching. The GBF contains a representation of the city which is composed of small reporting areas, usually based on tax, census, or voting tracts, and thus normally available from the city's data processing center. A typical reporting area contains four to six city blocks. Since the reporting areas are a convenient source on which to collect crime and other incident statistics, the geometry of police unit patrolling sectors is usually based on contiguous sets of these regions. Thus, the address of each call for service can be identified as being from a particular patrol unit's sector. This information is available in all CAD systems, and is automatically transferred to the dispatcher with the other incident data input by the complaint operator.

It cannot be expected that complaint operators will accurately spell every incident address which is input into the CAD system. Furthermore, it is often more convenient to locate an incident by some common name such as Hornblower Square or the Nimitz Building. A table of common

misspellings and equivalent names would greatly reduce unnecessary delays caused by manual verification of street spellings or transformations of common names into actual street addresses. This table can be used as a direct input to the geographic base file. Once a street name has been determined, the street number of an incident can be checked against the range of numbers on a particular street. For example, a call address of 71 Rockland Street would be invalid if Rockland Street only included address numbers from 101 to 399. An extension of this concept to include invalid street numbers within a range would of course be possible, but would require much more storage space for the geographic base file. This author's observations in a city where the number of false calls is very high, many of which involve invalid addresses within street number ranges, indicate that the increased storage space for such detail could be worthwhile. Observations have also revealed that such false alarms usually involve types of calls for service which are given high priority within the dispatching process, such as violent crimes or disputes involving weapons. In such cases, patrol vehicles travel to the reported area as quickly as possible, accompanied by sirens and flashing lights. The implications concerning citizen and police officer safety are obvious.

It is important to note at this time that the complaint operator would receive data on address verification and call validity on his CRT display prior to completing his conversation with the caller. In most cases he would query the caller about any discrepancies in the information supplied before entering the incident data into the dispatch queue.

Routines for checking call validity can be further enhanced with the addition of one file and a minor expansion of the GBF. The file would

contain all calls from a given address over some specified period of time, perhaps twenty-four hours, and would be automatically purged of old calls. Whenever a complaint operator input a new incident location, the file would be searched for recent calls from the same address, or in an area local to the new incident. If the search was successful, data from previous calls could be accessed by the operator or dispatcher to ascertain whether the new call should be considered valid, invalid, or a repeat of a recent call which is already in the dispatcher's queue. Call validity can also be assessed if an address classification is added to the geographic base file. For example, the report of a Breaking-and-Entering would not be consistent with an address classification of a vacant lot. Data concerning address classifications can also be valuable to the dispatcher and the patrolman, as will be discussed shortly.

A final method of determining call validity involves an interface between the geographic base file and telephone equipment. Generally, the area serviced by an urban police department encompasses several telephone trunk lines. Ideally, when the telephone trunk service areas form a mutually exclusive, collectively exhaustive set over the city, most calls originating in one trunk line service area would be considered invalid if the incident address reported fell in a different trunk line service area, subject of course to boundary conditions. Figure 6 depicts an example for the case of non-overlapping telephone trunk line service areas. The validity of a call for service from the shaded area, as determined by its trunk line of origin, would be suspect if the address given for the incident was at position (x_1, y_1), while address (x_2, y_2) would be entirely likely for that particular caller. Address coordinates

FIGURE 6: NON-OVERLAPPING TELEPHONE TRUNK LINES

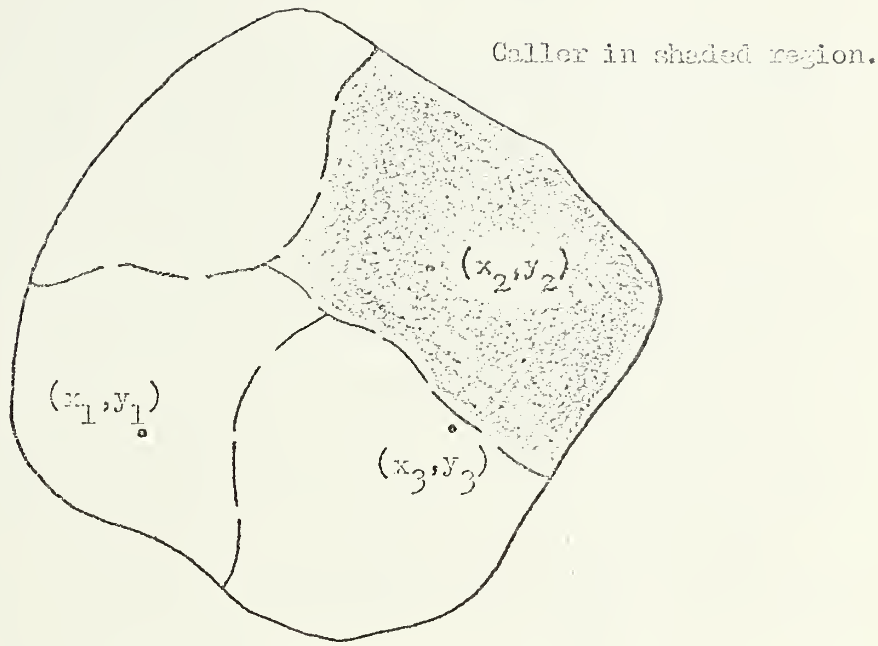
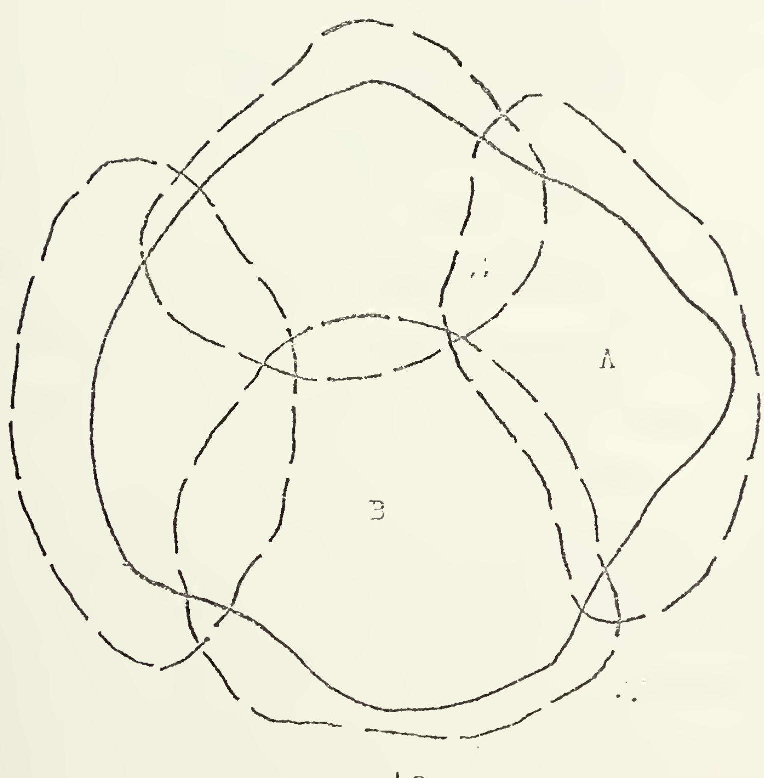


FIGURE 7: OVER-LAPPING TELEPHONE TRUNK LINES



(x_3,y_3), being close to its trunk line service area boundary, would have to be considered plausible, as the caller might also be next to the same service area boundary.

Figure 7 depicts the more typical case of overlapping telephone trunk line service areas. While the concept of checking call validity by the above method is still useful in this case, it does apply to a larger set of caller and incident locations, and the boundary conditions are obviously more complicated. For example, a caller from trunk line service area A might not even be within the police department's jurisdictional boundaries, and storage requirements would be increased by the need to identify more than one trunk line where overlapping occurs, as with areas A and B. An intelligent CAD system could make the above assessment quickly and easily.

As was noted in Chapter III, most police departments partition calls for service into a maximum of three priority classifications, normally corresponding to emergency, routine, and administrative police work. Significant gains can be realized in the management of queues and the assignment of patrol units to calls for service if the computer capability to easily maintain numerous priority classifications is utilized. For example, an administrative call to report a burglary on a Friday night, typically the busiest period for urban police, could easily be scheduled for service early in the next week at a time when patrol units are less busy. Valuable information of this sort is not readily available within a system maintaining only three or fewer priority classifications. An intelligent CAD routine would obviate the need for the complaint operator to memorize the priority classes. A routine which compares the incident

type code with a general operator-determined priority of emergency, routine, or administrative can be used to assist in the partitioning of incoming calls into numerous classes. Such a routine could also use information concerning repeat calls, recent calls in the same vicinity, and temporal patrol unit workloads in assessing call priorities.

As one last possible intelligent CAD routine to assist the complaint operator, a simple calculation of the estimated wait in queue of any particular call for service can be performed, and this information can then be given to the caller. While this type of routine can be useful in any case, it would be particularly valuable if the computer was used to assign one of many priorities to each call, as noted above, since some waiting times can be quite long in the latter instance.

4.3 Assisting the Dispatcher

The police dispatcher is charged with managing the queues of calls for service and determining patrol unit assignments to incidents. While mobile digital communications devices alleviate the burden of manual updating of unit status by the dispatcher and greatly reduce the time expended for voice radio transmissions, and hard-copy printers are used to produce radio logs automatically, the crucial dispatcher functions of determining unit assignments and maintaining call queues are largely overlooked by present CAD system designs. These problems are briefly addressed below.

4.3.1 Possible Solutions to Dispatcher Problems

As discussed in the previous section, an intelligently structured geographic base file is a valuable asset to a computer-aided dispatch system. For example, address classification data was noted as being useful to the dispatcher. If the dispatcher automatically received information that an incident address corresponded to a large building such as a high-rise structure, or a factory or warehouse, or an open area such as a park, where the chances of escape by a suspect were great, he might want to dispatch more than one patrol unit. Similarly, crimes in progress near concentrations of people, such as in a retail business or entertainment center, might warrant the dispatch of more vehicles. In cities with horse-mounted police, a park classification could signal the dispatch of the horseman, if on duty. Other useful classifications include residential, abandoned building, and vacant lot.

More importantly, a class of data concerning distances between locations in the city, crucial to the dispatching function, can be easily derived from the geographic base file. In particular, an incident location can be identified with its reporting district of origin. This information can then be used to enter a stored matrix containing a list of preferred patrol units for dispatch to incidents within each reporting district in the city. The status of each such unit can be ascertained, and the "best" patrol unit(s) for assignment to each call at any particular time can easily be determined by a simple computer algorithm. Use of this information would approximate a "modified-center-of-mass" dispatching strategy, noted in Chapter III to yield reduced response times

in comparison to the "strict-center-of-mass" strategy used by most police dispatchers.

As stated previously, the dispatchers in a typical urban police department have few restrictions on their dispatch assignments. While several operational computer-aided dispatch systems recommend unit assignments to the dispatcher, the choices are usually based only on narrowly constrained distance relationships such as the center-of-mass strategies noted above. While dispatchers have considerable latitude in determining which patrol unit to ultimately assign to a call for service, and need not necessarily send the computer's choice, there is no guarantee that the dispatcher's decision process will correspond to the desires of the police hierarchy. For example, this author has observed cases where units supposedly in reserve for special patrol purposes were assigned to calls for service at the dispatcher's discretion, even though a regular sector patrolman was available.[17]

Dispatch algorithms can readily be divised which will guide the dispatcher's decision making to be more consistent with departmental policies, and which take into account many more variables than the dispatcher could possibly consider. For example, if the department desires that the "closest" free unit according to the modified-center-of-mass always be dispatched to an incident, an intelligent CAD algorithm could accurately determine the proper unit, while the dispatcher could only estimate which one was closest. It should be apparent that departmental criteria for delivering service to the public must be determined in detail for intelligent dispatch algorithms to be successful. This concept will be addressed in Chapter VI. The possibilities

for intelligent dispatch algorithms are limited only by the police department's imagination, ability to establish detailed dispatch criteria, and desire for standardization of the dispatch process.

A prerequisite to the institution of intelligent dispatch algorithms is the detailed delineation of manpower and job responsibilities within the department. A system which contains information only on marked patrol vehicles is severely limited. At a minimum, patrol vehicles should be identified as regular sector patrol units, supervisor cars, special patrol units such as "wild", "umbrella", or "cover" cars,[18] squadrols or vans,[19] and unmarked vehicles. The purpose and manner in which these vehicles are dispatched depends heavily on their assigned use. Furthermore, foot patrolmen, horse patrolmen, auxiliary police,[20] and other similar units should also be included. While most police departments do not allow the dispatcher to control the assignments of Traffic Division and Tactical Force units, occasions such as serious auto accidents and emergency conditions might warrant the dispatch of these vehicles. At the beginning of each tour of duty, the units available and their assigned duties would be entered into the CAD system. Included could be special capabilities and characteristics of each vehicle and patrolman. This input was mentioned in Chapter III, and includes such items as special medical training of the police officer and weapons carried in each patrol vehicle.

While response time continues to be one of the major measures of performance for police services, many police administrators are altering the ways in which they evaluate the services which their department renders to the public. This fact would imply that police officials are

beginning to revise the criteria by which patrol units are assigned to calls for service. Two such strategies which tend to increase response times to at least low priority calls, as noted in Chapter III, are pre-emptive dispatching and the maintenance of neighborhood identity. As outlined below, intelligent CAD routines can readily incorporate these policies into the patrol unit assignment decisions of the dispatcher, and thus contribute to the standardization of the dispatching process.

Pre-emption is the removal of a police unit from a low priority job in order to attend to a high priority call for service.[21] As stated earlier, most urban police departments sanction the occasional pre-emption of patrol units when circumstances warrant. Pre-emption represents the committal of a police department as an emergency service agency, since increased waiting times for lower priority customers will occur, but the results of the survey described in Chapter III indicate that police departments have not adequately provided for pre-emptive command and control. While it is important that the dispatcher and patrolman maintain a high level of discretion in these situations, the official departmental policy concerning pre-emption of services can easily be programmed into the dispatch algorithm of a CAD system. The computational capabilities of the CAD system can be employed for assessing the utility of pre-emption in any particular circumstance, according to established criteria. Unit times in service, distance relationships, temporal and spatial crime patterns, queue information, and similar data can be computed, stored, and accessed when needed for such purposes. This would tend to routinize the dispatcher's decision process, without removing his discretion entirely. A common sense approach to pre-emption

would dictate that except for severe emergencies, the patrolman being pre-empted should evaluate the consequences of leaving his client, even temporarily. Ensuring that the pre-empted customer eventually regains service in a reasonable length of time is of the utmost importance, and would require some minimal level of queue control, also easily handled by an intelligent computer-aided dispatch system.

Current emphasis by police administrators on the establishment and maintenance of community or neighborhood identity with a particular patrolman or small group of patrolmen is strong. Although the "standard" dispatch algorithm defined in Chapter III would at first glance ensure some sort of sector integrity, practice indicates otherwise. Workloads for most urban police departments keep patrol units busy on the order of 20% to 40% of each tour of duty. Larson[22] argues that these units will be dispatched outside their own sectors a similar percentage of the time. The stacking of low priority calls for service by the unit assigned to their sector of origin will improve on the amount of time spent in a particular neighborhood, but creates the potential for extreme waiting times for low priority incidents. Chapter V presents an "intelligent" dispatch algorithm which compares the total time in service of each unit with overall service time statistics in reaching a decision on whether or not to stack low priority calls. As in the case of pre-emptive dispatch strategies, the capabilities of a computer to perform complex algorithms in rapid fashion is a valuable asset to the dispatcher and the department.

Besides standardizing the dispatch decision making process, the CAD system can be extended to routinize the emergency responses of the command and control network. A list of procedures to be followed and

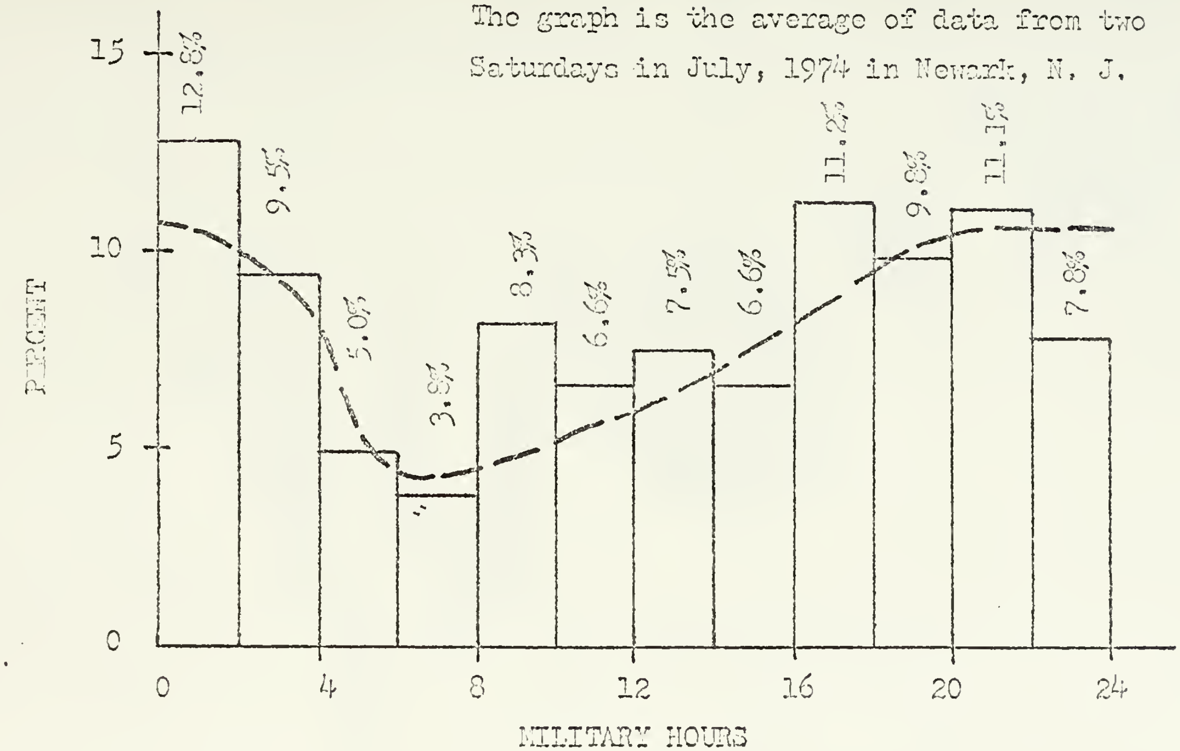
information valuable to the dispatcher in the event of an emergency could be stored. For example, persons on city departments to notify, with their telephone numbers, could be displayed on request. Requirements for equipment such as blockades and lighting, and the escape routes on which to locate it could be accessed. Finally, as part of a silent alarm file, data on building floorplans, alarm locations, and safe locations could be keyed to microfiche files, a system currently operational in a few urban police departments.

Larson's study[23] of the New York City Police Department workloads indicated a pronounced fluctuation of demand throughout a twenty-four hour period. Furthermore, weekend demands represent a sizable percentage of overall weekly calls for service. It can be postulated that efficient routines for dispatcher queue management can significantly improve the effective patrol manpower levels during peak periods of demand, and help to prevent conditions of local saturation of patrol force.

Figure 8 depicts a typical temporal study[24] of calls for service in an urban environment. Figure 9 summarizes data collected by Larson[25] which reveals the wide fluctuations in work activities of patrol units during a twenty-four hour period. Even a cursory study of these graphs would indicate that the stacking of low priority calls during peak demand periods for eventual dispatch during the hours of relative inactivity would improve the balance of patrol unit utilization.

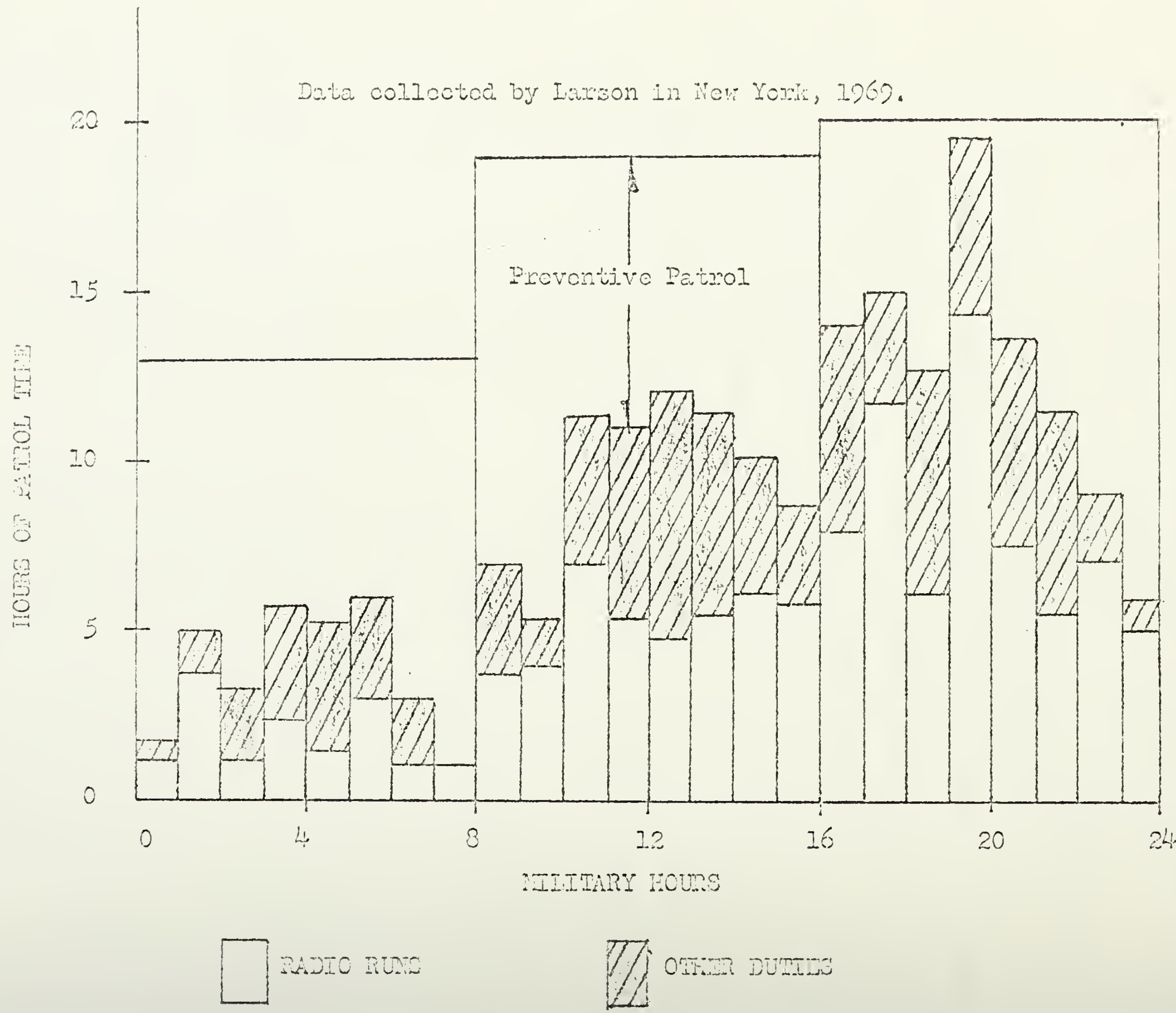
Once again, a simple computer-aided dispatch algorithm could manage this problem. For instance, each district, or group of sectors under a single command, might reserve a minimum number of free patrol units

FIGURE 8: TEMPORAL CRIME PATTERN



The dashed line estimates the actual crime pattern with shift-change phenomenon taken into account.

FIGURE 9: FLUCTUATIONS OF DEMAND FOR POLICE SERVICE



at all times, except in the event of dispatch to high priority incidents. Calls of the lowest priorities could be stacked for service by the patrol unit in whose sector the call originated, or thresholds could also be established on waiting times for calls of each priority. If the threshold was surpassed, any free unit could be dispatched to the particular call. Other strategies for handling the dispatcher's queue, as well as those mentioned, should be researched, and their respective operational feasibilities should be examined. All such strategies are, of course, compatible with CAD systems.

4.4 Assisting the Patrolman

Each patrol unit, whether on foot, horse, or vehicle, has three major duties. They are to freely patrol the assigned beats or sectors, to respond to calls for service when dispatched or when incidents are observed in the process of patrol, and to complete written reports as necessary. Each of these primary duties conflicts with the others. The problem areas of concern here are the hazards to the safety of the patrol officer, and the excessive paperwork required of the patrolman. Methods for queue management mentioned previously directly improve the scheduling of patrol duties, and hence, that problem will not be discussed.

4.4.1 Possible Solutions to Patrolman Problems

Patrolmen quickly gain a thorough knowledge of their assigned sectors, particularly of those locations which deserve cautious approach

when responding to calls for service, such as street gang hang-outs and rowdy taverns. Most urban police departments, however, do not restrict the dispatch of patrol units from one sector to another. The result is that a unit often can be sent to a section of the city of which he is not too familiar. Furthermore, even the sector unit patrolmen are not normally aware of all the addresses within their sector which appear on gun registrations, which have storage for explosives or flammables, or which are residences of people with serious prior police records.

In order to make police officers cognizant of possible danger at an incident location, a hazardous address file can be maintained off-line, with its member addresses flagged in the geographic base file. On request, the hazardous address data can be displayed and sent to the unit assigned to the call. Mobile digital communications capabilities ensure that this information can be transmitted on a timely basis.

While officer safety is the primary consideration in maintaining a hazardous address file, the potential for its misuse is great. As Colton[26] has observed, the computerization of law enforcement records has given officials a decisive means for controlling the lives of individuals. These issues of privacy must be considered whenever using a CAD system in this manner.

The command and control measure with undoubtedly the greatest influence on police officer safety is a method for monitoring patrol unit locations at all times. Automatic vehicle monitoring (AVM) systems are available which can continuously track police vehicles with extreme accuracy.[27] The cost of these systems, however, is prohibitive for

most police department budgets. Even for those departments which can afford an AVM system, the benefits gained might not substantiate the investment, as will be discussed in Chapter VI.

It is possible, however, to estimate patrol unit location by several methods. It is probably safe to assume that while on preventive patrol, a police unit is either equally likely to be at any location throughout its assigned sector, or spends more time in reporting districts with higher (perhaps, lower!) incident arrival rates. Thus, unless further information can be utilized, little accuracy can be expected in estimating patrol unit location.

However, by employing status information, estimated vehicle patrol speeds, dispatch data, and geographic base file relationships, an intelligent CAD system could project vehicle locations during certain periods of patrol. For instance, while returning to its assigned sector after being dispatched to another part of the city, a vehicle can be assumed to be on the best route back, traveling at some reasonable velocity. Such cases, while not rare, comprise an insignificant percentage of a patrol unit's tour of duty. In cases where the unit is dispatched within its own sector, however, the estimation of unit location through mathematical models is applicable to a longer portion of the unit's patrol. Determining the best method for estimating patrol unit location will require further research. Three possibilities for mathematical location models are outlined in Appendix 2. Such methods not only can provide a police department with an inexpensive means for improving officer safety, but might also prove useful in reducing response times in certain cases.

As one final strategy for increasing patrol officer safety in the field, the computer-aided dispatch system can be used to monitor the length of time since each patrol unit has reported a change in status. The two intervals of greatest importance are the time enroute to the scene of an incident and the on-scene service time. These periods can be estimated from travel time and service time statistics, respectively.

An important addition to an algorithm for monitoring status change intervals would be a system for updating the length of the expected period after initial communication. For example, consider a patrol unit which reported on the scene of an incident at time t_o. If the unit did not report back in service by time t_o+t_s, some time greater than the expected time of completion of the job, the CAD system would automatically flash a warning on the dispatcher's CRT display. After gaining radio contact with the patrol unit, the dispatcher would ascertain the unit's expected time of completion of the job, and update the tickler file.

Finally, the issue of reducing patrol officer paperwork is not so much one of intelligent CAD design, but more of an administrative reassessment of what data is actually desired and used by officials. However, the rapid printing capabilities of a CAD system can be capitalized upon to at least partially complete the incident reporting requirements of patrolmen. Much of the data needed can automatically be printed, such as incident sequence numbers, locations, type codes, arrival and service times, and completion status. At the end of each tour, the patrolman involved could add any comments necessary, and sign the report.

4.5 Assisting the Police Administrator

The two administrative functions of foremost importance to the dispatching function are the strategic deployment of scarce patrol resources, and the monitoring of system performance. However, as noted in Chapter III, current command and control procedures do not provide for the efficient allocation of resources, certainly not for the dynamic case. Furthermore, police officials do not in general receive information concerning the status of the patrol force in a timely fashion. In fact, the dispatcher, who is at the bottom of the police hierarchy, is the only member of the department who has such knowledge. The following section presents possible strategies for alleviating these problems which rely on the computer's rapid printing and computational capabilities.

4.5.1 Possible Solutions to Administrator Problems

Court appearances, illness, vacations, vehicle maintenance, and special assignments all create a situation of varying, often unpredictable, levels of patrol resources. At least one major urban police department attempts to alleviate this problem by fixing the number of patrol vehicles, and replacing missing drivers with regular foot patrolmen or supervisors. This strategy obviously only displaces the problem.

Several authors[28] have developed either analytic or simulation models which determine optimal patrol areas for police units. All of these models are inadequate for <u>real-time</u> computer-aided dispatching

due to their core requirements and length of run-time. As a result, the models are more suited for long-term, strategic resource allocation than for tactical considerations.

The repositioning strategy outlined below is one possible means for allocating scarce patrol resources which is ideally suited for use by an intelligent CAD system on a real-time basis. It incorporates conceptual features of both long-term resource allocation models and fixed vehicle resource strategies, yet is applicable to both routine and emergency conditions which cause patrol resource variations.

As stated in Chapter III, most urban police departments handle temporary shortages in patrol resources by either assigning more than one sector to a particular unit, or assigning the vacated area to a supervisor car, an "umbrella" car, or a "wild" car, if one is available. Work by Larson[29] and Jarvis[30], among others, has shown that these strategies yield both increased response times and imbalanced workloads compared to other strategies for the same number of available patrol units.

As an alternative to strategies currently in use by urban police departments, it is suggested that several sets of patrol sector designs for a city be determined, using one of the available long-term, strategic resource allocation methods, which are based on a range of available patrol resources. Each of these sector plans could be stored off-line. At the start of each tour of duty, the CAD system dispatch algorithms would be initialized with the proper sector plan, based on the number of available units and assignments of each. Whenever routine fluctuation in manpower occurred, such as for vehicle maintenance or scheduled

court appearances of a patrolman, the sector plan could be altered. As Larson[31] points out, strict criteria for repositioning units must be detailed by each police administration. Certainly one criterion would be the expected length of time during which the shortage applied. In a system with mobile digital terminals, the proper sector plan could be transmitted to each patrol unit automatically. Other systems could rely on contingency manuals.

Repositioning for emergency conditions such as fires, large traffic or industrial accidents, and bank robberies would require only slight modifications from the routine repositioning of forces. Two considerations are of primary importance. First, dependent on the extent of the emergency, units other than the vehicles and foot patrolmen normally dispatched through the CAD system will be available. Namely, fire engines, ambulances, Traffic Division, S.W.A.T., and Tactical Force units might be needed on the scene of the emergency incident. Second, while the need to maintain some minimum level of routine police service throughout the city should be considered, the number of units required for the emergency condition is of primary concern.

One could intuit that the deployment strategies described above would be no harder for the patrolman to adapt to than present policies. The effects on issues such as neighborhood identity are harder to determine, but probably are insignificant. Of course, the reductions realized in response times should be profound.

The capability exists within an intelligent computer-aided dispatch system framework for the collection and analysis of statistics on all facets of the dispatching and patrol processes. Reports can

be automatically generated for police administrators on a <u>timely</u> basis, either at regular intervals or on request, allowing the capability to make decisions concerning patrol force deployment when needed, such as during conditions of local saturation of the patrol force.

Urban police departments will inevitably be serviced by the universal 911 phone system. Peg count registers for each complaint operator position can be monitored to determine the number of calls arriving at each position, the number of calls experiencing delays, the number of calls transferred to the secondary switchboard, and similar statistics.[32] While current procedures call for the recording of these peg count registers by hand, Bell Telephone has recently agreed to a direct equipment interface with one police computer-aided dispatch system presently being built.

The incident data entered by the complaint operator can be used to initiate a complete set of statistics on police service. Included are data on the following:

i) Temporal crime pattern (Including type and priority).
ii) Sector workloads.
iii) Intra-sector spatial crime patterns.
iv) Repeat calls, calls from hazardous addresses, etc.
v) Additions to CAD files such as the Common Misspellings and Hazardous Address Files.

On passing through the dispatch algorithm, the incident data could be used to generate statistics such as the number of calls entering the

system under conditions of zero car availability. Upon dispatch, the following statistics could be determined:

vi) Communications Room delay.

vii) Unit initially assigned to call.

viii) Back-up units assigned.

ix) Intersector dispatches.

Status information and clearance of the incident would establish:

x) Travel times.

xi) On-scene service times.

xii) Unit Workloads.

xiii) Follow-up actions such as arrest.

xiv) Completion of incident report data.

Other data useful to police administrators which would be available include the number of police-initiated activities in the field and items which complete the patrol tour composite, such as vehicle maintenance, court appearances, and meal breaks.

While reports which are produced on a monthly basis or longer can be fairly cumbersome, it is extremely important that daily and weekly reports be concise and readable to ensure their use by decision makers. One way to accomplish this goal is to develop a set of thresholds by which to compare the statistics collected. Only those extraordinary events which surpass the established limits would be included in the

report. For example, excess average service time of one particular unit might indicate evasion of duties (or perhaps dedication to the public!), or specially dense spatial crime patterns in one area could indicate criminal ring activity. Extreme care must be taken to prevent threshold data from becoming performance criteria which the patrol force attempts to satisfy to the exclusion of providing adequate police service to the public.

4.6 Summary

This chapter has presented numerous possible solutions to problem areas within the dispatching process which are based upon the more efficient utilization of the capabilities of current CAD system hardware. Many of these "intelligent" CAD routines rely on the development of a detailed geographic base file. Such a file is particularly valuable to the complaint operator, whose functions in the dispatching process have been largely over-looked by present CAD system designs.

The computational abilities of the computer were noted as being indispensible for the standardization of the dispatch decision process among dispatchers and between the dispatcher and departmental policies. Complex algorithms which incorporate strategies such as pre-emptive dispatching can easily be employed to guide the dispatcher's choices for patrol unit assignments. Particularly important is the computer's ability to manage queues of calls for police service, including the capability to incorporate departmental policies on the scheduling of service to low priority calls during periods of reduced demand.

When the data storage capabilities of the computer are combined with the rapid communications of mobile digital devices, the potential to improve patrol officer safety is greatly enhanced. For instance, information concerning hazardous addresses can be transmitted to patrolmen while enroute to such locations, allowing them to prepare themselves prior to arrival on the scene of an incident.

The ability of the computer to handle dynamic situations can be capitalized upon to provide for the efficient allocation of scarce patrol resources. Finally, CAD system rapid printing capabilities can be used to transmit information concerning the status of patrol forces to police administrators on a timely basis, and to produce statistical analyses of performance data on patrol force operations and personnel.

It is difficult to evaluate the suggestions presented herein, as many are qualitative in nature. The intent, however, has not been to prove the utility of any of the mentioned routines, but only to demonstrate some of the potentials of computer-aided dispatch systems.

It is important to note that the programming costs of these routines is negligible, as that function can be accomplished by in-house technical personnel. Operating costs, however, are a different matter. Many "intelligent" CAD algorithms are used on all calls for service; others, such as call-stacking routines, are employed primarily during periods of peak demand. Hence, computer processing can become a significant factor in the total waiting times of calls for service. To avoid this situation, the police administrator will at some point in the development of an intelligent computer-aided dispatch system be

forced to make a trade-off between the benefits gained from employing advanced dispatching algorithms and the costs of expanding the computer core space. Furthermore, this discussion has assumed the ability to rapidly transmit data between the dispatcher and the patrolman. For departments without a mobile digital communications capability, then, even minor use of "intelligent" dispatching algorithms can require considerable hardware expenses.

CHAPTER V

ADAPTIVE DISPATCH STRATEGY

5.1 Introduction

The previous chapter comprised a general outline of methods for intelligent computer-aided dispatching. It would be useful at this point to examine in more detail one specific patrol force deployment strategy available to police administrators which can incorporate departmental policies through the utilization of statistics collected and employed by an intelligent computer-aided dispatch system.

The present section develops a strategy which can significantly increase a patrol unit's neighborhood identity without appreciably effecting the average wait in queue of calls for service. The particular strategy involved is termed "adaptive" dispatching. It is a method of stacking low priority complaints in queue, for service by the patrol unit in whose assigned sector the incident originated, which is based on a consideration of the chance that the particular unit will be free soon, given the amount of time the unit has been in service on its current job.

This chapter contains a discussion of some reasons for employing adaptive dispatching, and an outline of the algorithmic logic involved. Due to the analytic intractability of the problem, simulation techniques were used to assess the feasibility of the adaptive dispatching strategy

described. An analysis of the results of the simulation are included.

5.2 Why Use Adaptive Dispatching?

While the technology of the automobile and the radio have greatly increased the effectiveness of police departments in combatting crime, it has caused a decline in the familiarity of the public with their local police patrolman. This problem has contributed to the decrease in confidence and support of urban police over the past few decades. In recent years this lack of neighborhood identity has been recognized by police administrators, but efforts to improve the situation have centered on Team Policing projects. The basic idea behind the Team Policing deployment strategy is to decentralize the police command and to despecialize the functions of police officers. The technical expertise of investigative units such as the Fraud Squad is sought only as a last resort, with the local patrolmen doing the brunt of the investigative work. The hopes of administrators are that crime will decrease as a result of improved police-community relations. Unfortunately, the success rate of Team Policing projects is extremely low.[33] One reason for the failure of Team Policing has been that such projects require an increase in manpower which police budgets cannot withstand.

A possible solution to this problem is to maintain a centralized command and control network, vital in responding to emergency situations, yet use the capabilities of that control to deploy police units in such a way as to gain maximum neighborhood identity with minimal

effect on the overall response time of the police to calls for service. Simply reducing the amount of intersector dispatches will unfortunately not satisfy the requirements of this problem, since indiscriminate stacking of calls can greatly increase the waiting times of those calls in the dispatcher's queue. The proposed "adaptive" dispatching strategy attempts to make a more "intelligent" decision regarding the stacking of calls in queue by considering the length of the present period of service.

In order to develop an understanding for the usefulness of knowledge concerning the total time a patrol unit has been busy on one particular job, consider the three probability density functions depicted in Figure 10, each having an average of thirty minutes. The exponential density function given in Figure 10A is commonly known as a memoryless process.[34] Note that the shape of the function is unaltered by information regarding time spent in service. As expected, the probability, P, of completing service in the next δ minutes, given t minutes of service already completed, is independent of t. That is,

$$P = 1 - e^{\delta/30} \quad , \delta \geq 0.$$

As will be elucidated later, the decision process for adaptive dispatching is dependent on the probability P. Hence, little value can be gained from the knowledge of the length of the present period of service if the service time distribution is exponential.

A second-order Erlang density function is shown in Figure 10B. There is about a 50% chance that service will be completed in less than twenty-five minutes for this particular function. Unlike the

FIGURE 10A: THE EXPONENTIAL DISTRIBUTION

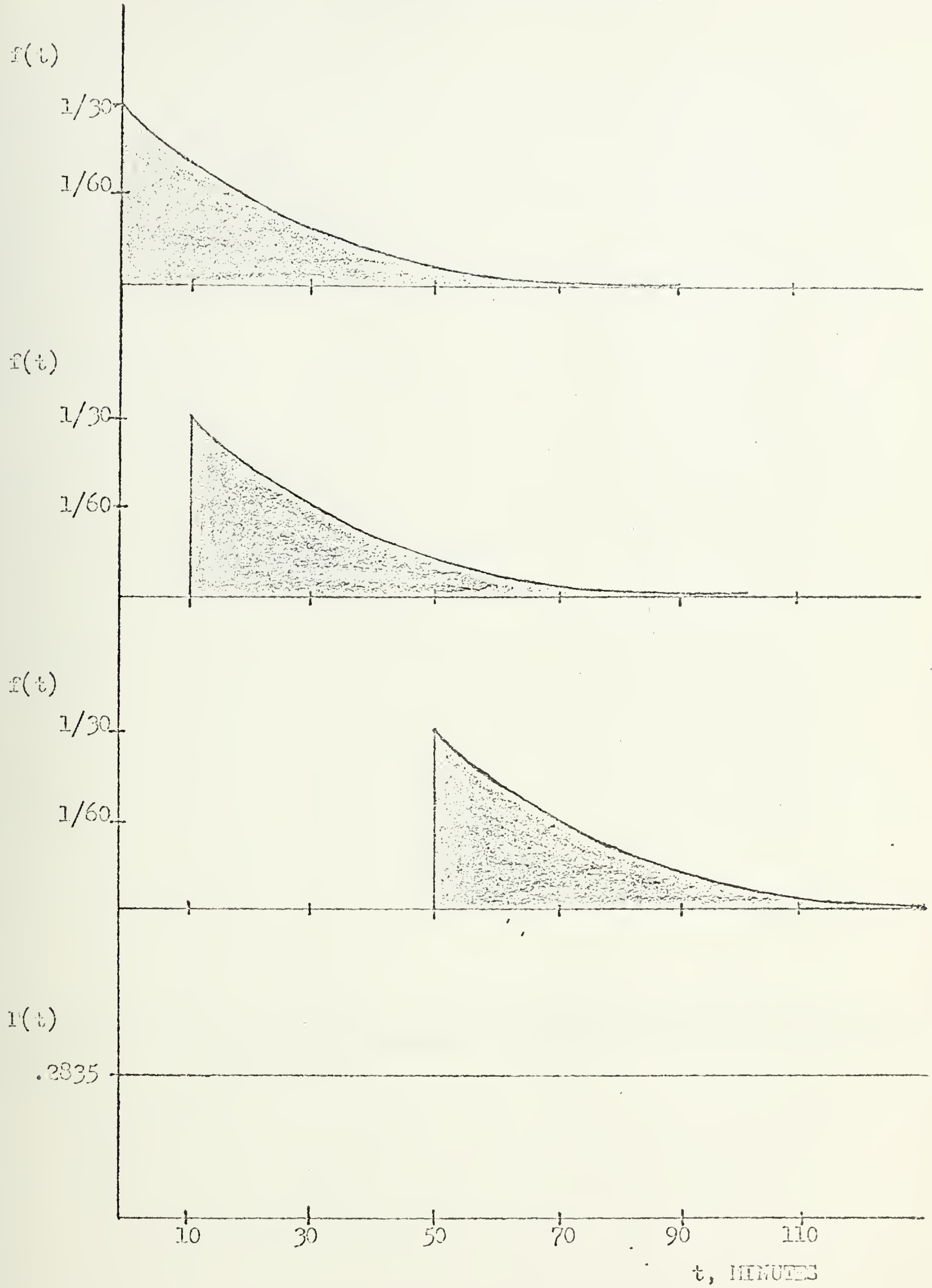


FIGURE 10B: THE ERLANG DISTRIBUTION

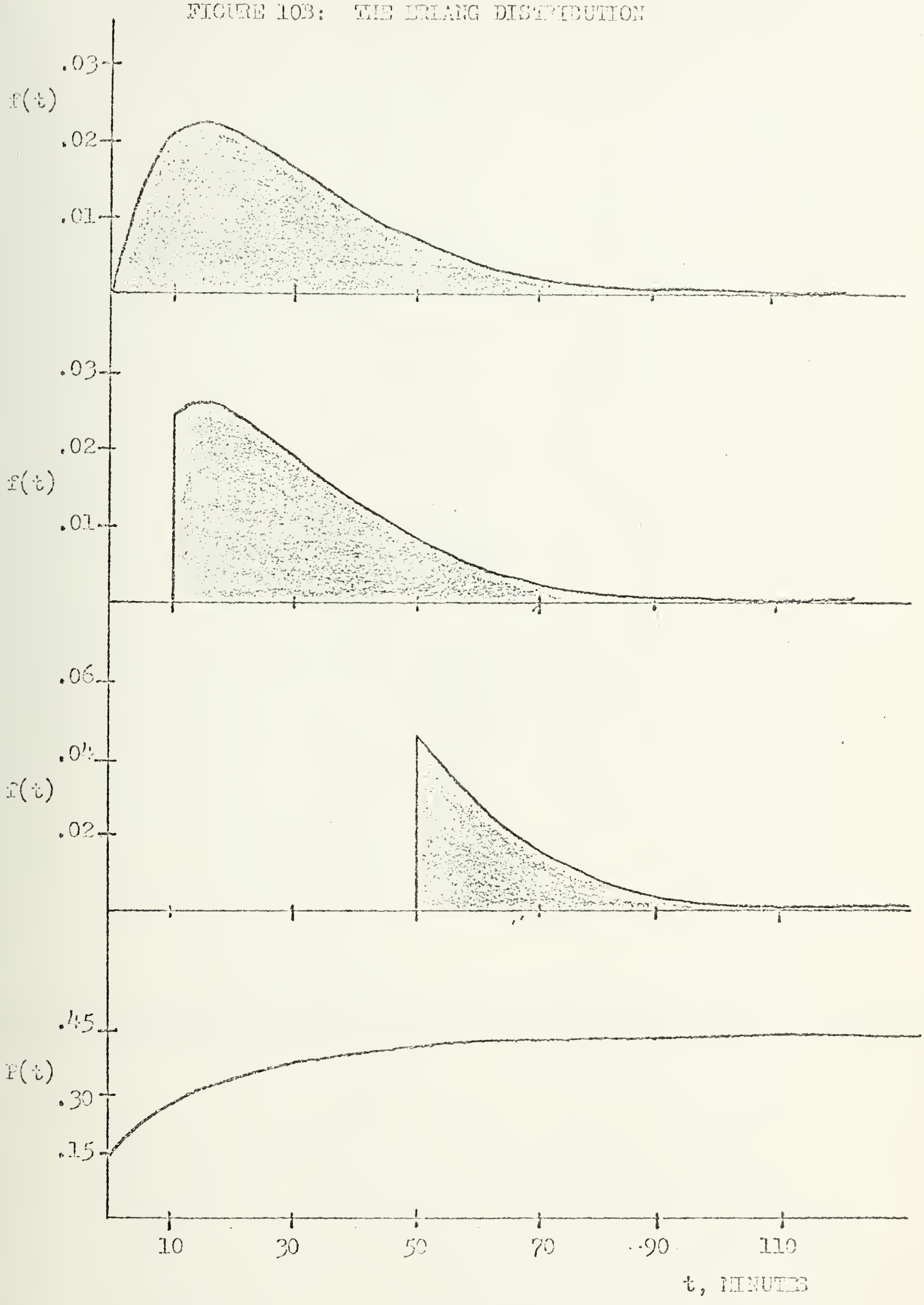
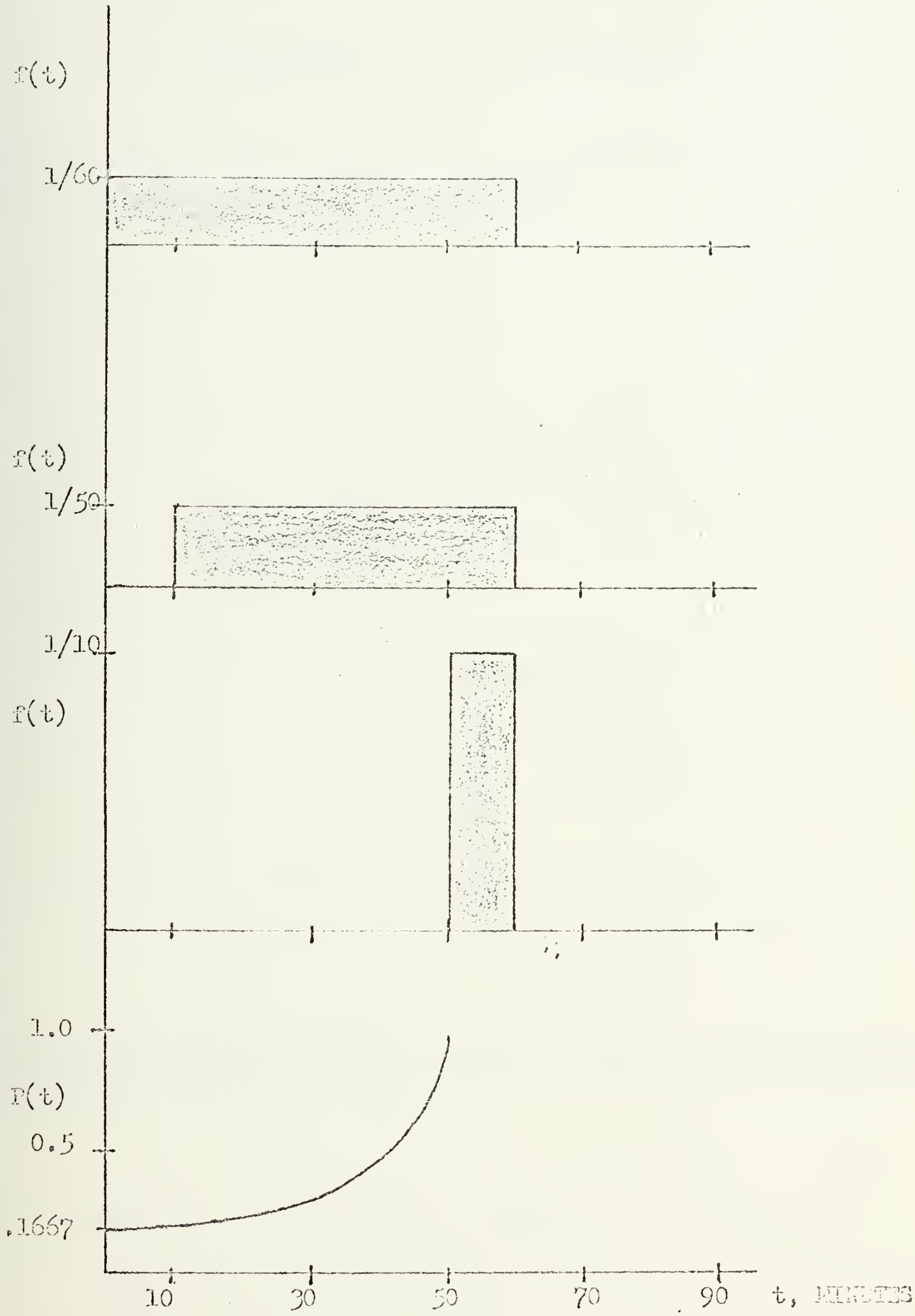


FIGURE 10C: THE UNIFORM DISTRIBUTION



exponential density function, the probability, P, increases as time in service, t, increases:

$$P = 1 - \frac{(15 + t + \delta)}{(15 + t)} e^{-\delta/15}, \quad \delta \geqslant 0 \text{ and } t \geqslant 0.$$

Furthermore, the usefulness of knowing the value of t decreases as t increases. In fact, as t approaches infinity,

$$\lim_{t \to \infty} P = 1 - e^{-\delta/15}, \quad \delta \geqslant 0,$$

which is independent of t.

Finally, consider the uniform density function depicted in Figure 10C. For this function, service must be completed by sixty minutes. Knowledge of the time in service increases in value as t approaches $(60 - \delta)$ minutes, since:

$$P = \delta/(60 - t) \quad , \quad \delta \geqslant 0 \text{ and } 0 \leqslant t \leqslant (60 - \delta).$$

Note that at t equal to $(60 - \delta)$ there is a 100% chance that service will be completed in the next δ minutes.

Although police service distributions are not uniform in time, it is reasonable to expect that service will be completed eventually. Hence, at least near the maximum length of service, knowledge of the service time already completed can be useful information, as exemplified by the uniform distribution above.

5.3 The Adaptive Dispatching Strategy Algorithm

The basic algorithm for adaptive dispatching is detailed in

this section. It represents an easily programmable decision process for determining the desirability of stacking a call for service in queue for the eventual assignment to the patrol unit of the call's sector of origin. The strategy is therefore not only a method for patrol force deployment, but also for the management of queues.

In order to use adaptive dispatching, the computer-aided dispatch system must maintain a file of the actual service time distribution for each priority classification, and must record status changes, particularly the time when each unit begins and completes service of an incident. Furthermore, each department must establish a set of parameters which indicate the utility of stacking a call in queue. A specific example of the general algorithm which follows will be presented in the next section.

Consider a system with N patrol units, each assigned to a single, non-overlapping sector, such that unit j is assigned to sector j, where $j = 1,2,\ldots, N$. Calls for service are assigned one of K priority classifications, where $k = 1$ denotes the highest priority. Assume that no queues currently exist, and that a call for service from sector j has just arrived. The following assignment policy is employed:

i) Assign the call to unit j if it is free.

ii) If unit j is busy on a priority k call for service, is there a reasonable probability that it will be free in the next δ_{jk} minutes?

iii) If (ii) holds, queue the call for service by unit j as soon as it is available.

iv) If (ii) does not hold, assign the call to another unit which is free.

v) If no units are presently available, queue the call for service by the first free unit.

When applying the above basic algorithm, the following rules will be adhered to:

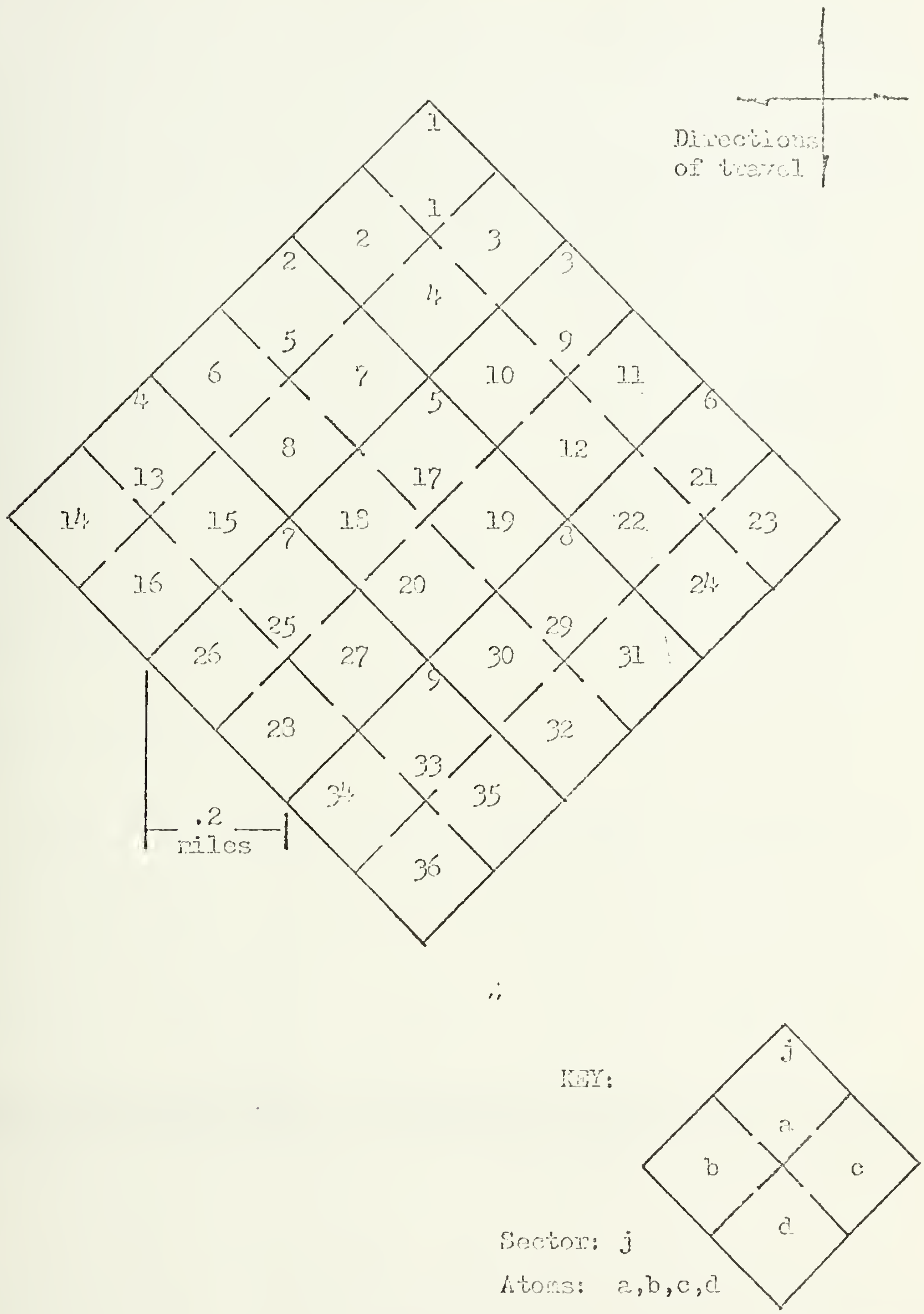
vi) High priority calls ($k = 1,2,\ldots, h < K$) will not be stacked by the above method, but simply queued for service by the first available unit. Hence, when a busy unit j completes service on a call, it will be assigned to any high priority calls in queue, on a first come, first served basis by priority. This rule applies regardless of whether or not a call has previously been stacked for service by unit j.

vii) If no high priority calls are in queue, unit j will serve any calls stacked for it prior to servicing any other low priority calls ($k = h + 1, h + 2,\ldots, K$) in queue.

viii) No more than one call may be stacked for service by each particular unit at any one time. Hence, no more than N calls can ever be stacked for the entire collection of sectors.

ix) In order to increase the response to high priority calls, a fixed number M of patrol units will be held in reserve for high priority incidents, regardless of the number of lower priority calls waiting in queue. The reserve units are not pre-designated, but depend on which (N-M) units become busy first, where N equals the total number of patrol units available.

FIGURE 11: MODEL PATROL DISTRICT



5.4 The Simulation Model

While the above strategy is fairly simple in concept, it is extremely difficult to model by analytic methods. In order to demonstrate, therefore, that adaptive dispatching can significantly increase the amount of time a particular unit spends in its assigned sector without appreciably increasing the average waiting time in queue of calls for service, simulation techniques were employed. Computer runs simulating the dispatching process of a model police department were made over a range of patrol unit utilizations, or workloads. The output was then analyzed to determine the increase in waiting times and decrease in intersector dispatching experienced when the adaptive dispatching strategy was used.

5.4.1 The Model Data Base

Figure 11 depicts the sample police patrol district used for the model. Each of the nine sectors is divided into four atoms, or reporting districts, throughout which the assigned sector unit patrols uniformly when not busy. The dimensions of each patrol sector were chosen to ensure a reasonable density of police units. This was accomplished by assuming that, at an average velocity of twelve miles per hour,[35] it would be desirable to travel from one atom center to an adjacent atom center in one minute. Hence, each atom has an axis of two-tenths of one mile. Travel is assumed to be right-angle as indicated, and velocities are considered equal in both directions.

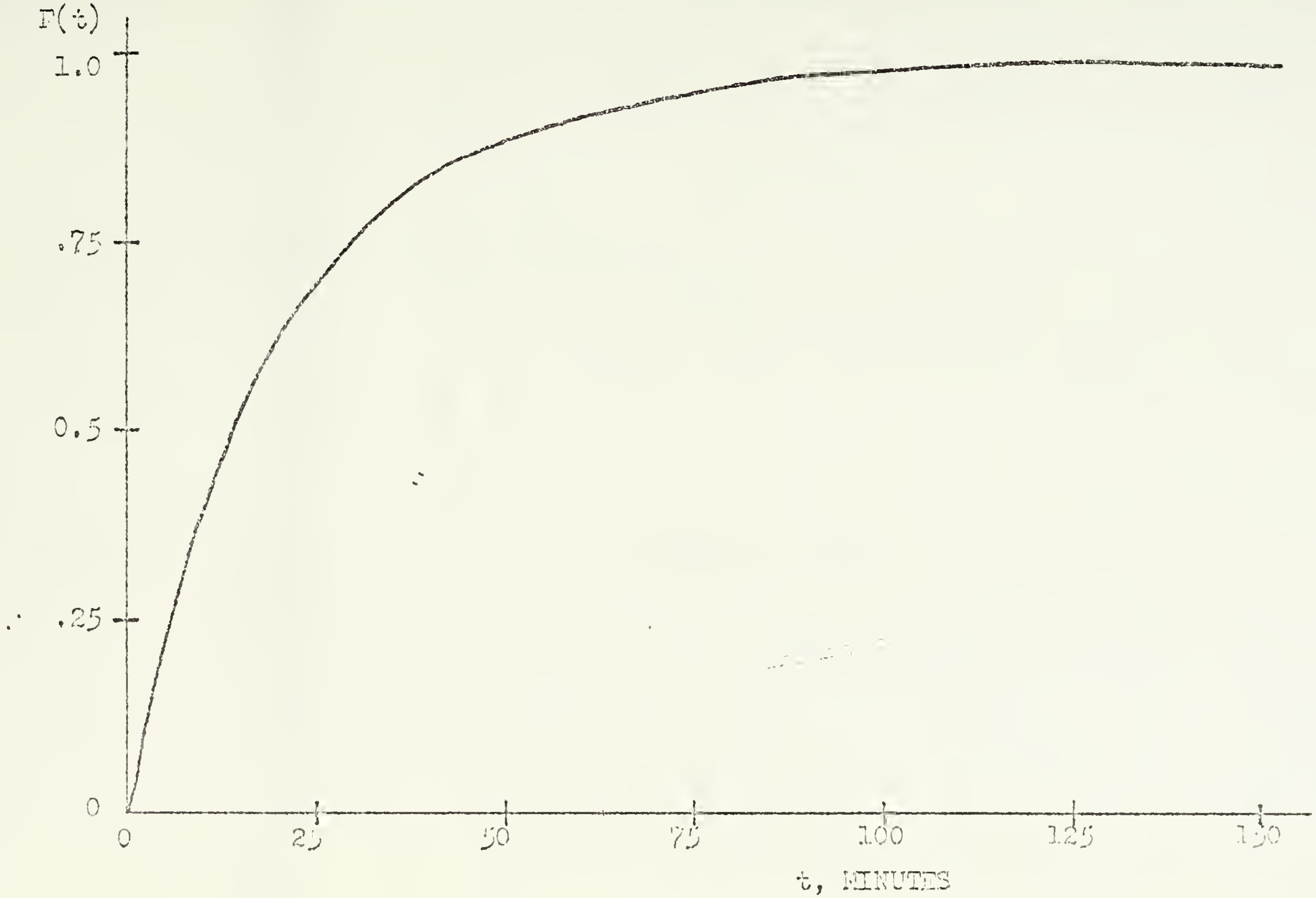
A fixed preference dispatch matrix, displayed in Appendix 3, was used to determine unit assignments. Hence, for example, a call for service from atom 12 would first be assigned to unit 3 if available, and thereafter to units 6, 8, 5, and so on. Entries in the matrix were chosen not only to minimize expected travel times, but also to eliminate the burden of central location.[36] Assuming an equal call arrival rate from each atom, the regular geometry of the sample patrol district provided for near-optimal sector design in terms of travel distance and balanced unit workloads. This feature was desirable in order to minimize the effects on waiting times and intersector dispatching of factors other than adaptive dispatching.

The geometry of the model patrol district also allowed a reduction in the storage requirements for the travel time matrix. The initial matrix has thirty-six rows and columns. Assuming that the travel time between atoms j and k are equal in both directions causes the matrix to be symmetric about the main diagonal. The patrol district geometry creates additional symmetry about the opposite diagonal, since, for example, atom thirty-six can be viewed as a mirror image of atom one. Appendix 3 contains the reduced matrix and an algorithm for its use.

The time between calls for service was generated by the exponential distribution function. Three priority classifications were used. This author's previous work indicated that a maximum of five percent of all calls can be classified as emergency, priority one complaints, seventy percent can be assumed to be routine, priority two incidents, and the remaining twenty-five percent are administrative, priority three calls,

FIGURE 12: THE CUMULATIVE SERVICE TIME DISTRIBUTION

Data collected in the Newark Police Department, 1974.



as representative values for one particular urban police department.[37] This information was then used to generate several sets of calls for service, each set representing a different patrol unit utilization, and each set used as input to both the base simulation run <u>without</u> adaptive dispatching, and the corresponding runs <u>with</u> the adaptive dispatching strategy. Call locations were drawn from a distribution which was uniform over all atoms in the district.

Larson[38] has shown that the exponential probability distribution is also useful analytically for modeling the length of service on each incident. Unfortunately, this model is inadequate for adaptive dispatching due to its property of being memoryless. That is, the probability of completion of service in the next δ_{jk} minutes is unaltered by information that the patrol unit has already completed t_j minutes of service on a particular call. To avoid this situation, an actual service time distribution from an urban police department[39] is employed in the model. The cumulative distribution is depicted in Figure 12. It can be easily determined that the probability , P_k^a, of unit j completing service on a priority k call in the next δ_{jk} minutes, given the total length of service already spent, t_j, is:

$$P_k^a = \begin{cases} \dfrac{F_k(t_j + \delta_{jk}) - F_k(t_j)}{1 - F_k(t_j)} & \text{if } 0 \leq t_j \leq t_{max}^k \\ \text{Undefined} & \text{otherwise} \end{cases}$$

where $F_k(t)$ is the cumulative distribution function of the service time for a priority k call, and t_{max}^k equals the maximum service time for the same priority classification, k. The adaptive dispatch criterion is

said to be satisfied when $P_k^a = P_k$, the level established by the police administration. Computer operations can be saved by observing that:

$$\frac{F_k(t_j + \delta_{jk}) - F_k(t_j)}{1 - F_k(t_j)} = \frac{(1 - F_k(t_j)) - (1 - F_k(t_j + \delta_{jk}))}{1 - F_k(t_j)} ,$$

and storing $(1 - F_k(t))$ instead of $F_k(t)$.

The model used assumes that for the three priority classifications, $F_1(t_j) = F_2(t_j) = F_3(t_j)$, and that each unit j has the same service time distribution. Furthermore, it is assumed that $\delta_{jk} = \delta$ and that $P_k = P$, for all units j and call priorities k. In actual practice, the lower bound of t_j can be determined for any department's service time distributions and choices of parameters P_k and δ_{jk}. For the particular service time distribution used in this model, the adaptive dispatch criterion for choices of P = .50 and δ = 15 minutes is satisfied when t_j belongs to either of the closed ranges (0,9) or (74,120). The fact that two ranges exist is not unusual for service time distributions, as will be discussed in Section 5.4.4. Generality was maintained for the model, however, by calculating the actual value of P_k^a at each iteration and comparing it to an arbitrary threshold of P_k = .50. Hence, if P_k^a is greater than P_k = .50, the criterion for stacking a call has been satisfied.

The model also assumes that no patrol units are available during the first ten minutes, or last twenty minutes of each tour of duty, except for the service of priority one calls. Only the latter two priority class calls can be stacked through adaptive dispatching. The first ten minutes of each shift are necessary for roll-call and the changing

of personnel and equipment; the last twenty minutes account for the practice of dispatchers and patrolmen not to assign or be available for dispatch to any calls near the end of a tour of duty.[40]

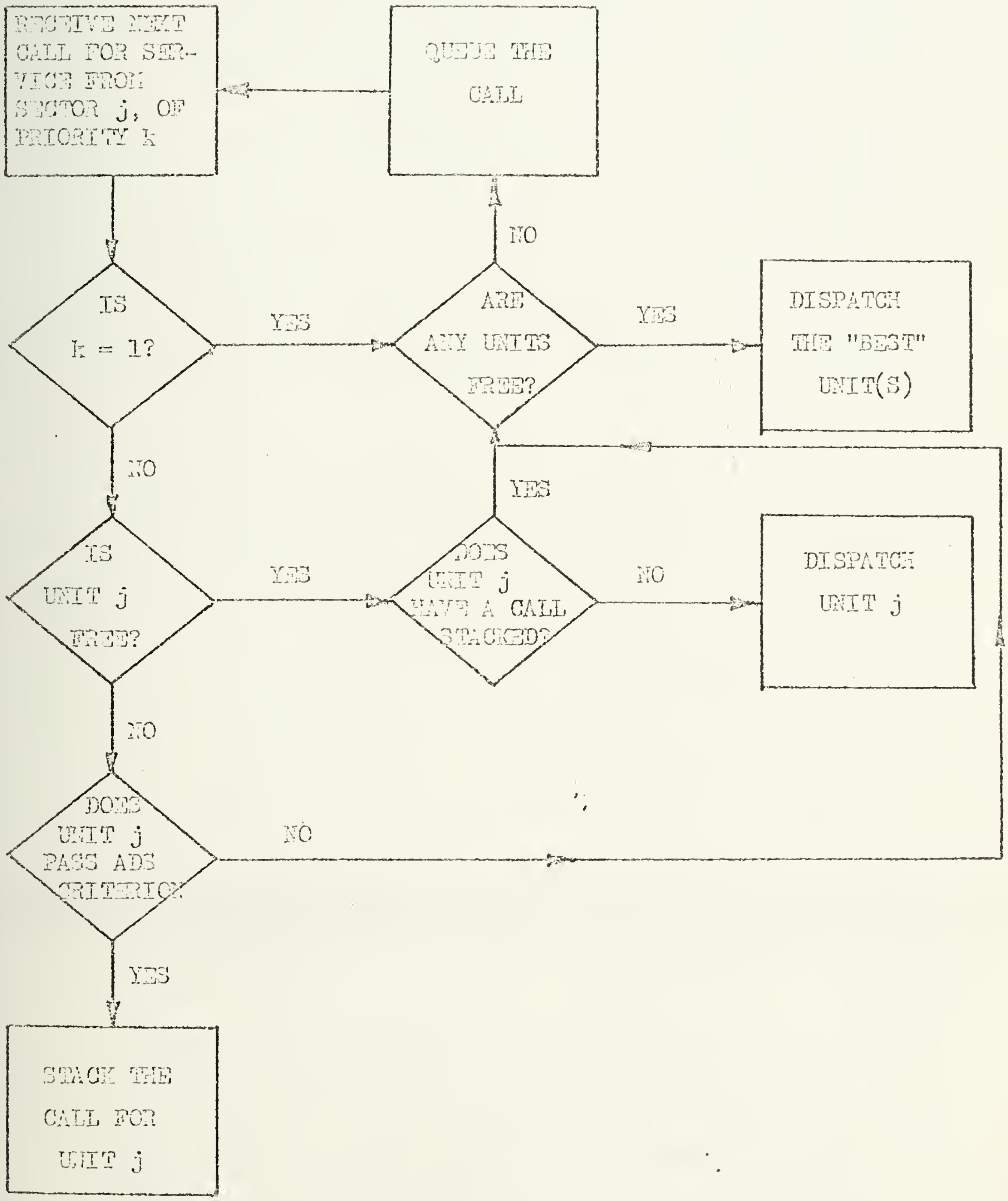
A flow graph of the logic of the simulation is given in Figure 13. The basic computer program is contained in Appendix 4. It provides for three separate simulations of the dispatching process: one <u>without</u> adaptive dispatching, and two <u>with</u> adaptive dispatching, for parameters choices (P,δ) equal to (.50, 15) and (.50, 30). The first set of parameters is considered to be a "reasonable" selection allowing adaptive dispatching a little less than half the time, while the second set represents the case of maximum allowable stacking of calls for service, allowing adaptive dispatching whenever possible for the particular service time distribution used.

5.4.2 Testing the Model

Several computer runs of the model were made during debugging of the program which were designed to test the accuracy of the logic of the simulation against the theoretical design. None of these or any successive runs produced counter-intuitive results.

A lengthy run of the model was performed for an average patrol unit utilization of about 54% in order to ensure stability of the model and to determine how many incident dispatches needed to be simulated to obtain a desired level of accuracy of the output statistics. A total of 3076 incidents over a ten-day period were simulated. Basic results of queuing theory[41] indicate that steady state conditions can be realized if the average utilization, ρ_{avg}, is less than one.

FIGURE 13: ADAPTIVE DISPATCH LOGIC



A little thought will indicate that a quick check that the number of calls in queue at the end of successive periods does not accumulate is sufficient to ensure that the model is stable. Figure 14 depicts the cumulative statistics for the average wait of priority two incidents. Note that the average wait stabilizes to within 3% of 6.40 minutes after 1200 incidents have been simulated. Note also that fewer than 200 incidents are necessary at this utilization level to produce results within two minutes of the steady state value. The standard error of the estimate was calculated to be equal to 0.36 minutes for this run. Twenty-four hour periods were used to determine this value in order to negate as much as possible the statistical dependency of successive periods.

As it is desired only to demonstrate that adaptive dispatching does not cause "unreasonable" increases in average waiting time, it was decided to make numerous short simulation runs of about 500 incidents over a wide range of utilization ratios, ρ_{avg}. The resulting statistics were plotted, and curves fitted to the data. The cumulative results of the long run at $\rho_{avg} = .54$ were then compared to the curve to reveal that the average wait determined by the two methods was within a two-minute interval for both priority two and three calls at that particular utilisation ratio. Typical values of ρ_{avg} for urban patrol units fall between 0.20 and 0.40. Since expected waiting times in queue decrease as ρ_{avg} approaches zero, one can intuit that the deviation of the model statistics from the true values will decrease in this range. The two-minute interval is therefore adequate for the purposes of this paper.

FIGURE 14: THE CUMULATIVE STATISTICS FOR PRIORITY TWO CALLS

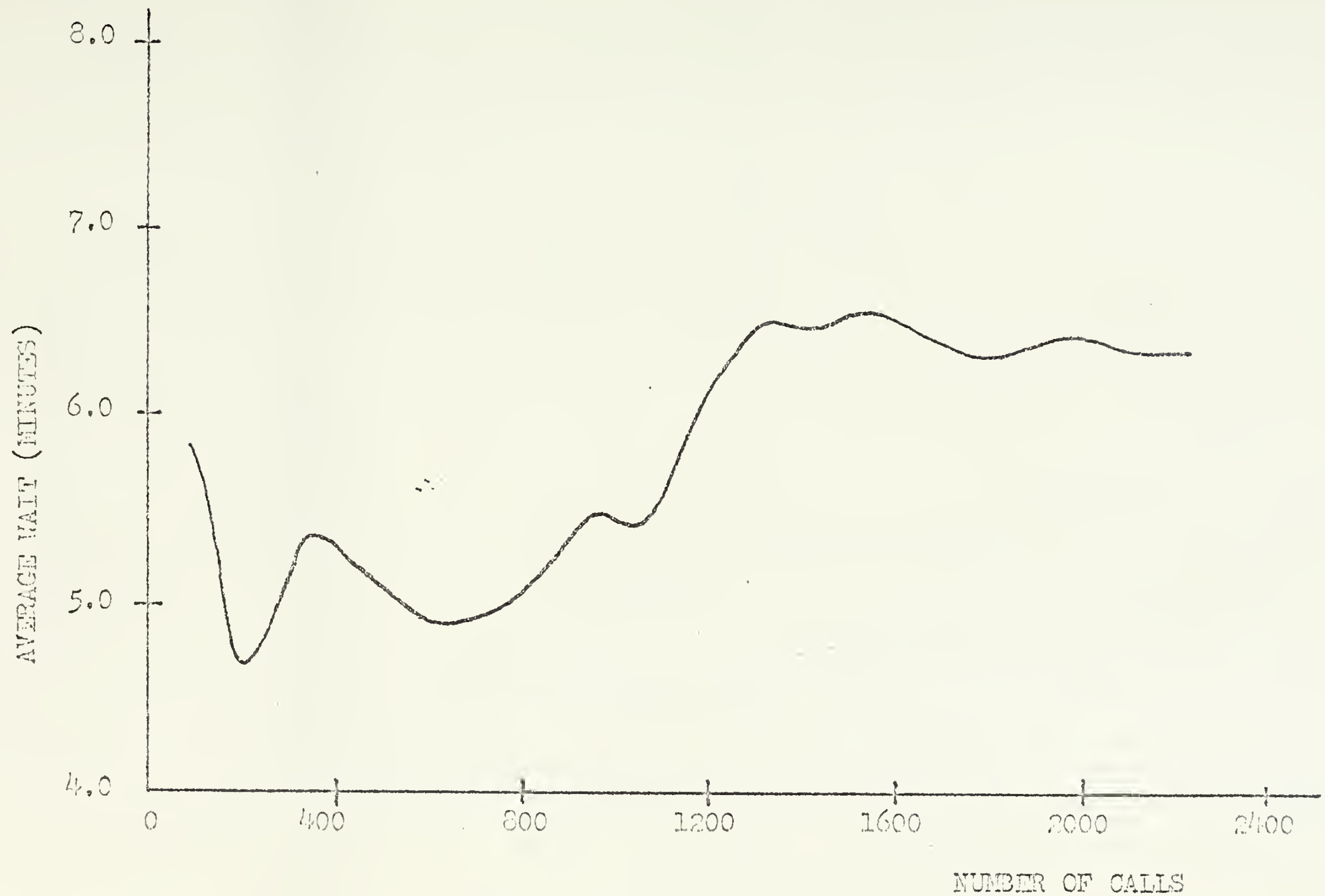


FIGURE 15: AVERAGE WAIT FOR PRIORITY TWO CALLS; TWO RESERVE UNITS

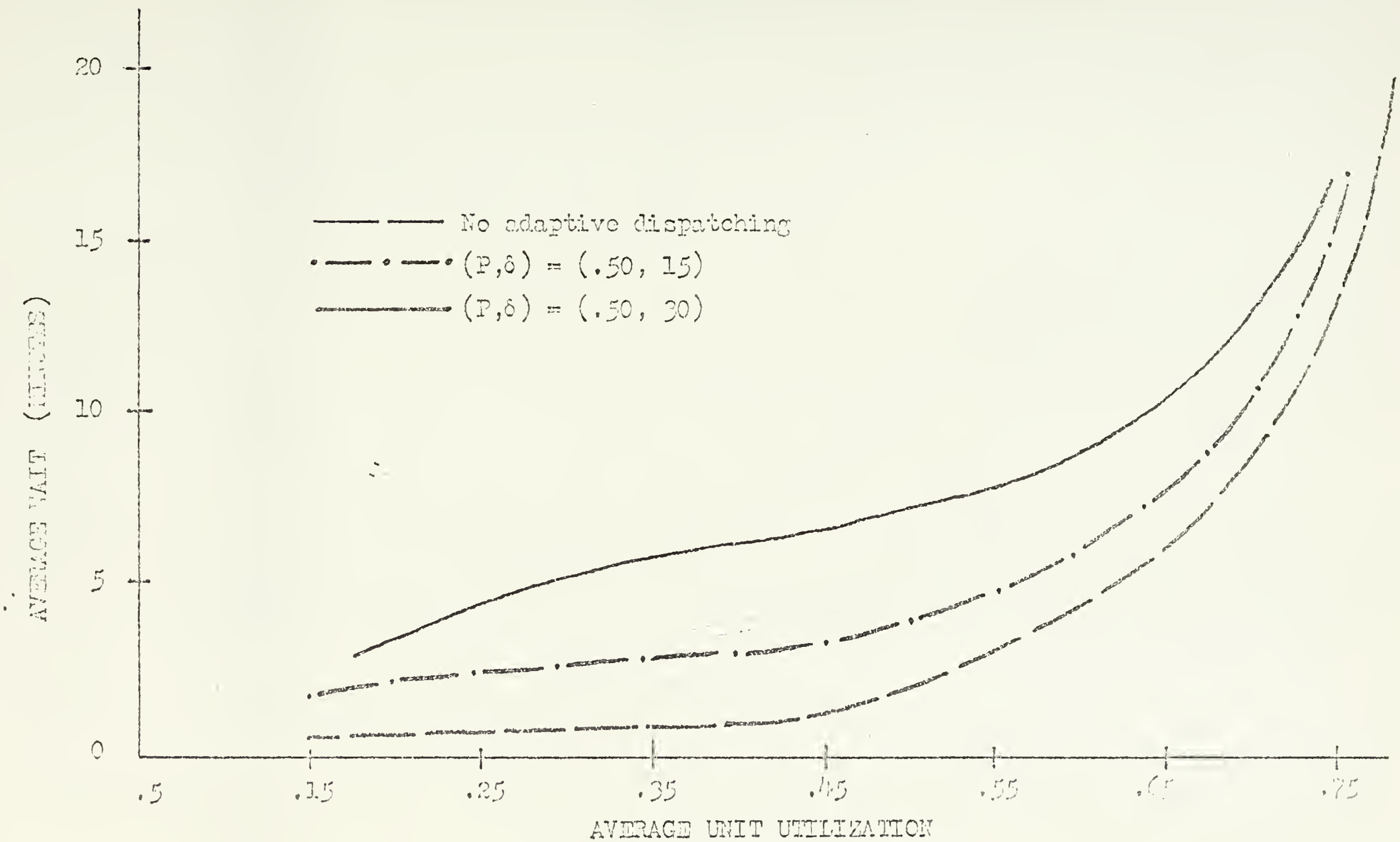
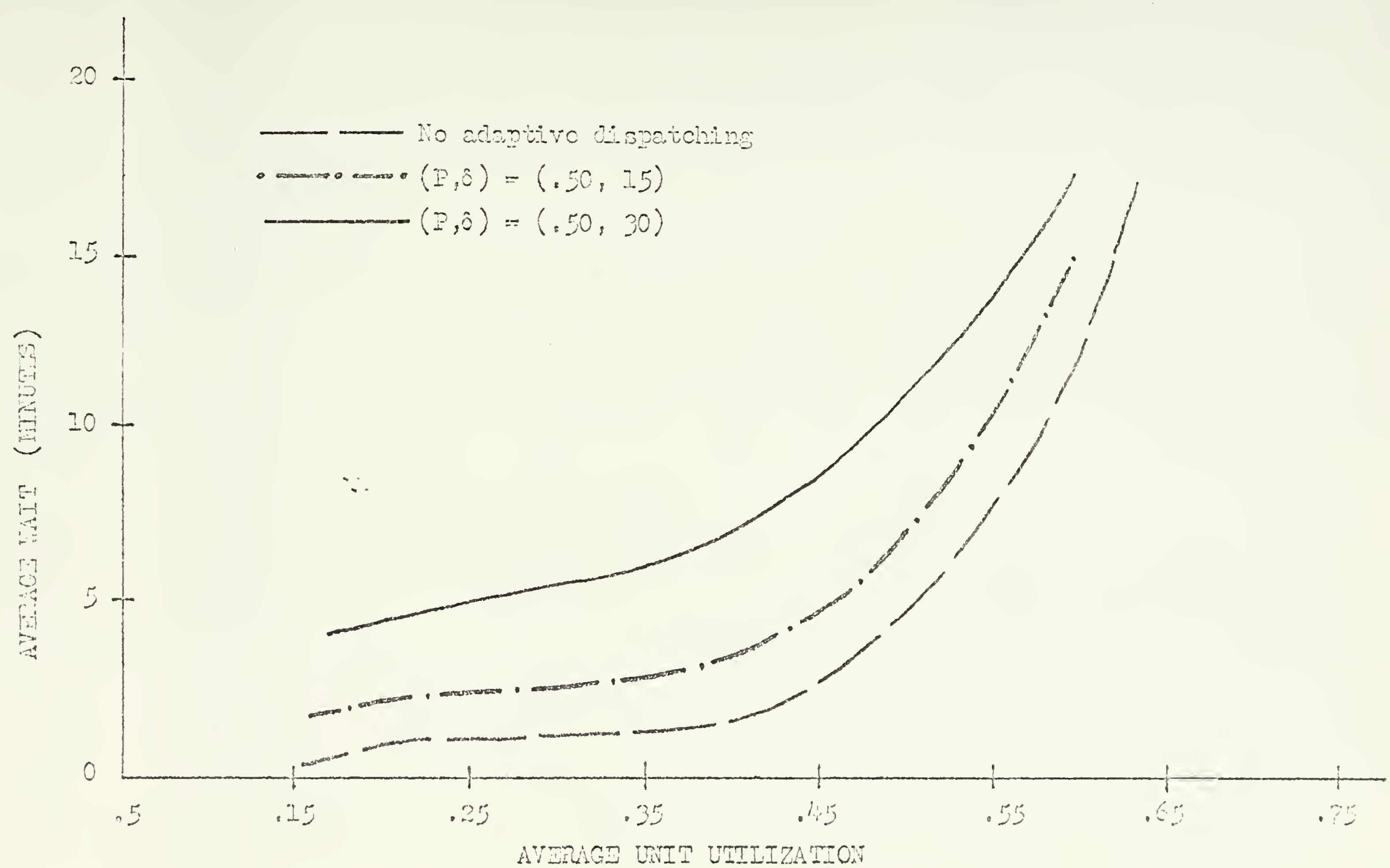


FIGURE 16: AVERAGE WAIT FOR PRIORITY THREE CALLS; TWO RESERVE UNITS



5.4.3 Statistical Output

Figures 15 and 16 depict data of the average wait in queue for priority two and three calls as a function of average patrol unit utilization. Two reserve units were used, allowing each priority one call to be served immediately in virtually all cases due to the low arrival rate of these calls. The three curves on each graph correspond to situations of no adaptive dispatching, and adaptive dispatching for choices of parameters P and δ of .50 and 15 minutes, and of .50 and 30 minutes, respectively. Note that in the common range for the average utilization ρ_{avg}, of .20 to .40 that a reasonable choice of adaptive dispatch parameters increases average wait in queue by no more than two minutes for both priority two and three calls. As expected, the average wait under an adaptive dispatch strategy approaches that of a non-adaptive policy as ρ_{avg} approaches either zero or one. As ρ_{avg} approaches one, the units are almost always busy, and significant queues can exist, while as ρ_{avg} approaches zero, there is only a small chance that a call will arrive in a unit's sector during the period when it satisfies the adaptive dispatch criterion. Table 2 summarizes data for values of ρ_{avg} between .20 and .40. Note that while <u>average</u> waits experience only small augmentations under adaptive dispatching, the increases in <u>maximum</u> waits can be large. For example, adaptive dispatching for the case when (P,δ) equaled (.50, 15) caused an increase in the average wait of 1.9 minutes for priority two calls and 1.76 minutes for priority three calls, while the <u>maximum</u> waits experienced over the given range for ρ_{avg} increased by 61.5 minutes and 32.6 minutes, respectively. Furthermore, a significant number of calls stacked

TABLE 2: SUMMARY OF SIMULATION OUTPUT[T1]

TWO RESERVE UNITS

	PRIORITY TWO CALLS			PRIORITY THREE CALLS		
	No ADS[T2]	(.50,15)[T3]	(.50,30)	No ADS	(.50,15)	(.50,30)
Average wait in queue	1.07	2.97	5.20	1.61	3.37	5.94
Maximum wait in queue for calls not stacked by ADS	27.1	26.7	27.1	30.0	23.2	24.0
Maximum wait in queue for calls stacked by ADS	N/A	88.6	101.6	N/A	62.6	80.0
Percent of calls exceeding wait threshold[T4]	.062	.128	.194	.029	.058	.110
Percent of all calls stacked by ADS	N/A	.137	.244		PRIORITY TWO AND THREE DATA COMBINED	
Percent of ADS successes[T5]	N/A	.408	1.0			

Notes:

T1. Data averaged over values of ρ_{avg} between .20 and .40. All times given in minutes.

T2. Adaptive dispatching strategy (ADS) not used.

T3. Ordered pairs signify adaptive dispatch criterion parameters (P,δ).

(cont.)

TABLE 2 (cont.)

NO RESERVE UNITS

	PRIORITY TWO CALLS			PRIORITY THREE CALLS		
	No ADS	(.50,15)	(.50,30)	No ADS	(.50,15)	(.50,30)
Average wait in queue	.717	3.06	5.57	1.12	3.67	6.18
Maximum wait in queue for calls not stacked by ADS	27.3	26.4	26.9	24.7	22.4	22.4
Maximum wait in queue for calls stacked by ADS	N/A	33.5	26.9	N/A	56.1	78.5
Percent of calls exceeding wait threshold	.043	.124	.198	.022	.061	.113
Percent of all calls stacked by ADS	N/A	.145	.274			
Percent of ADS successes	N/A	.428	1.0		PRIORITY TWO AND THREE DATA COMBINED	

Notes:

T4. Waiting time thresholds were arbitrarily set at one minute for priority two calls and twenty minutes for priority three calls.

T5. Each time that a call is eligible for stacking and the adaptive dispatch criterion is met counts as a success.

experienced waits which were longer than the arbitrarily chosen acceptable thresholds for each priority class of one, five, and twenty minutes, respectively.

Figure 17 and Table 2 contain similar data for the case when no units are held in reserve. As expected, the amount of adaptive dispatching increases in this situation. The result is a twenty-five percent to seventy-five percent decrease in the percentage of intersector dispatches, as shown in Figures 18 and 19. It is particularly interesting that the adaptive dispatch parameters can be chosen so that <u>the percent of intersector dispatch is less than half the utilization factor[42] while average wait in queue of calls for service remains below six minutes.</u> For (P,δ) equal to $(.50, 15)$ and ρ_{avg} between .20 and .40, the average wait in queue increased by less than 3.5 minutes over the case without adaptive dispatching. The low arrival rates and the fact that priority one incidents have preference over stacked calls resulted in only one case in over a thousand in which a priority one call had to wait for service. For average unit utilization above forty percent, however, one would expect the frequency of queued emergency calls to rise. Figure 20 depicts the percent reduction in intersector dispatches and the percent increase in waiting time over a range of values for ρ_{avg}.

5.4.4 Sensitivity of the Simulation Results to Model Parameters

The results of the simulation can be considered quite insensitive to the particular geometry of the model and the assumption

FIGURE 17: AVERAGE WAIT IN QUEUE; NO RESERVE UNITS

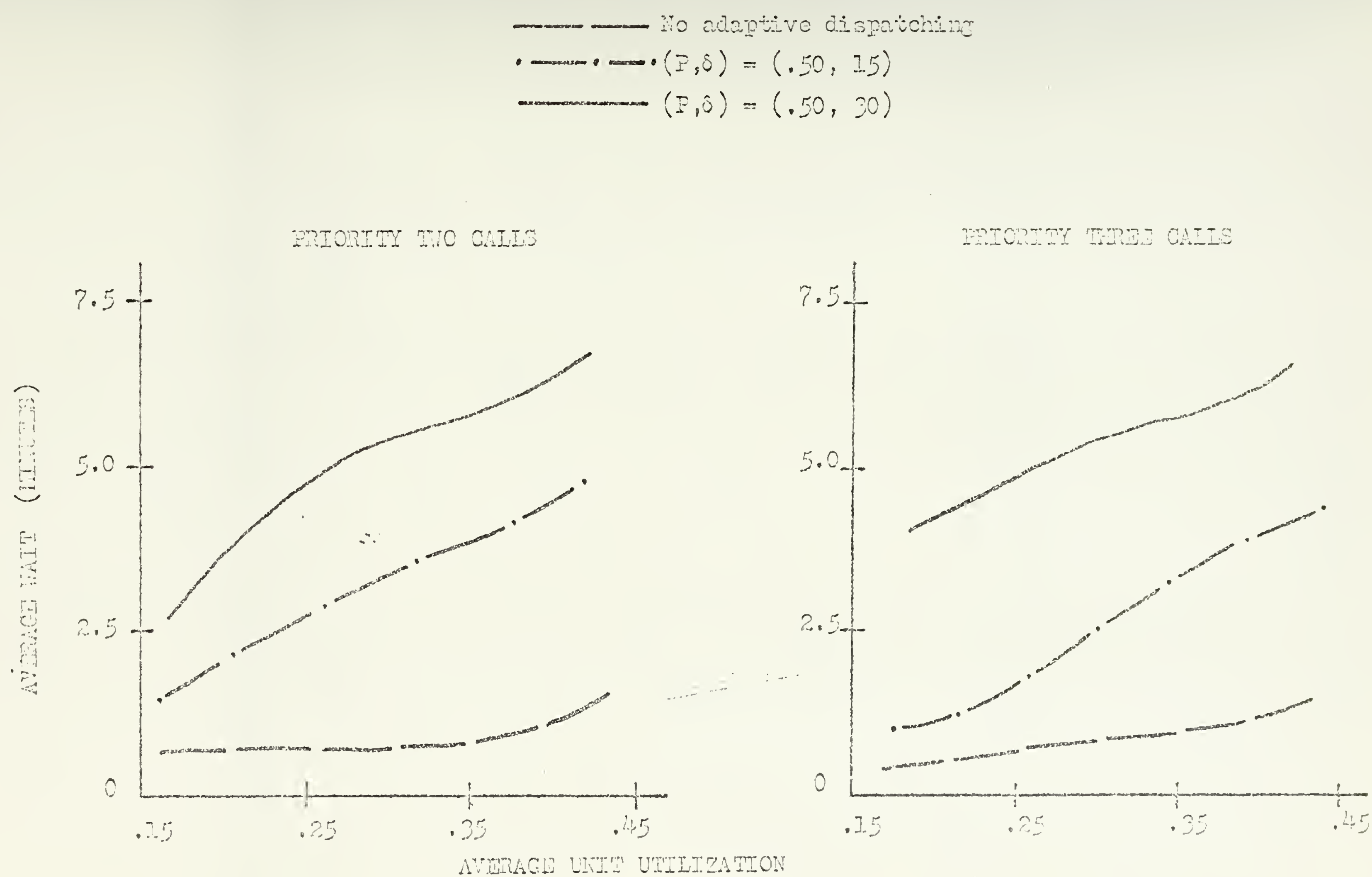


FIGURE 18: PERCENT OF INTERSECTOR DISPATCH
PRIORITY TWO CALLS

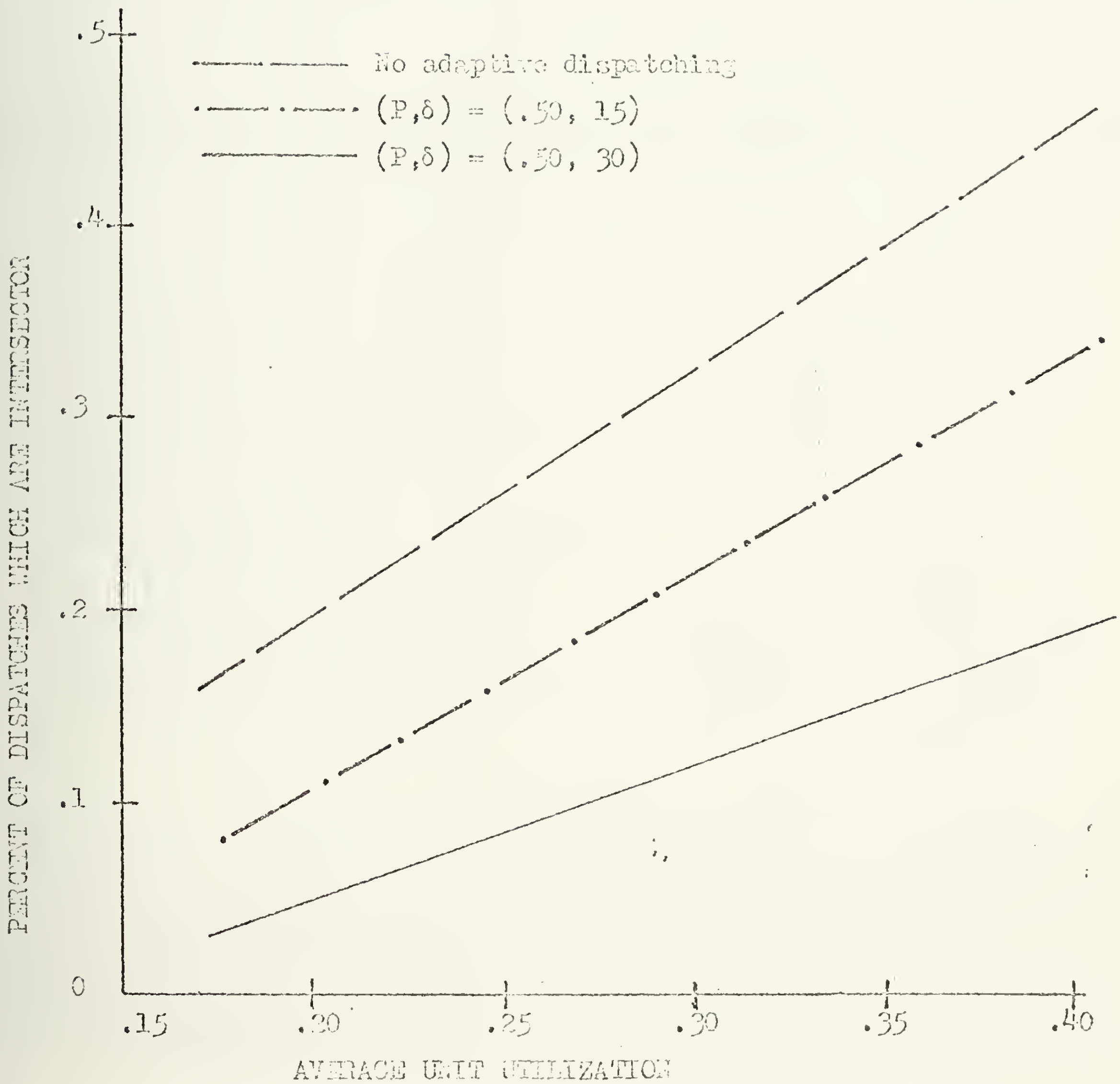


FIGURE 19: PERCENT OF INTERSECTOR DISPATCH
PRIORITY THREE CALLS

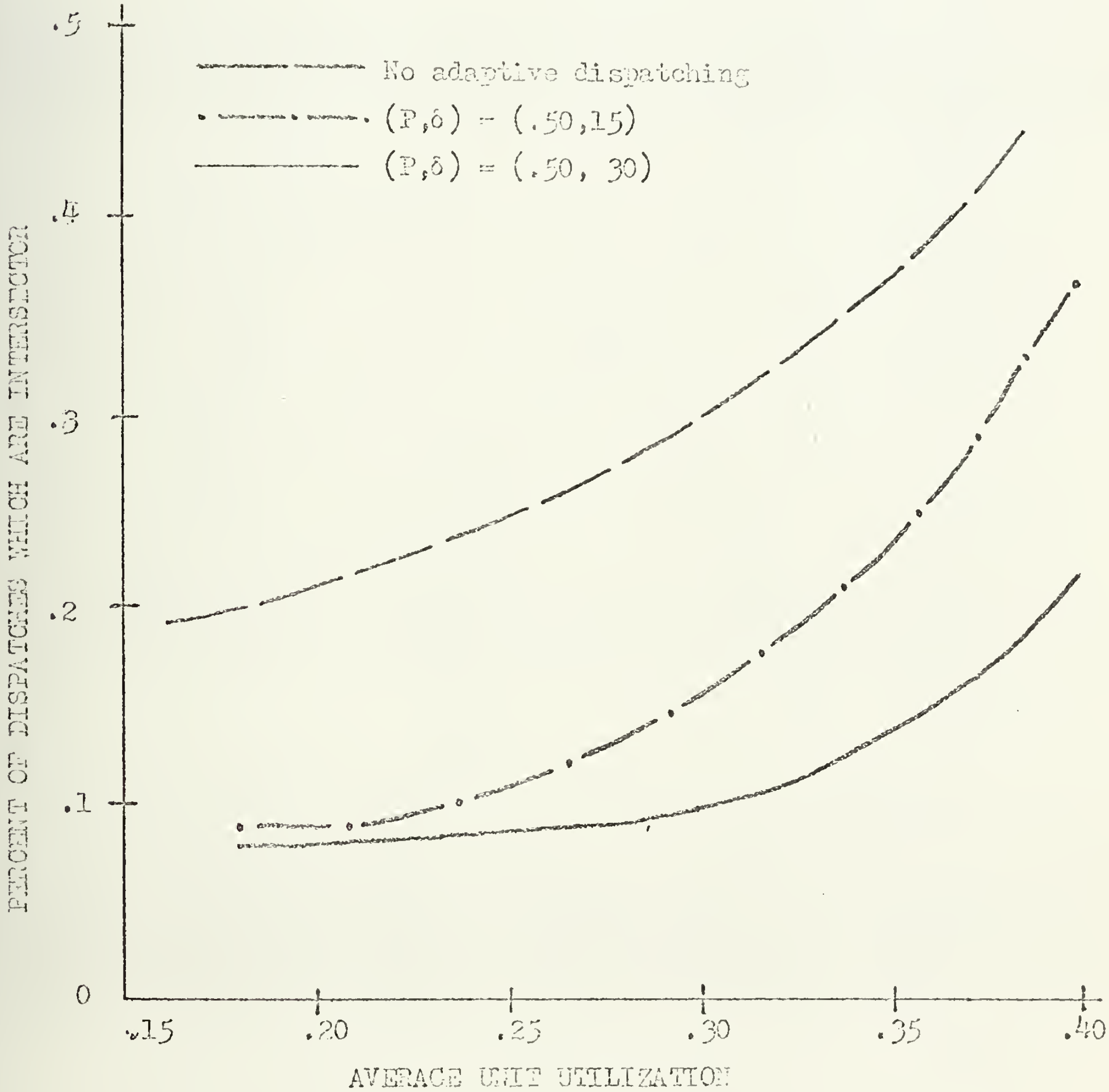
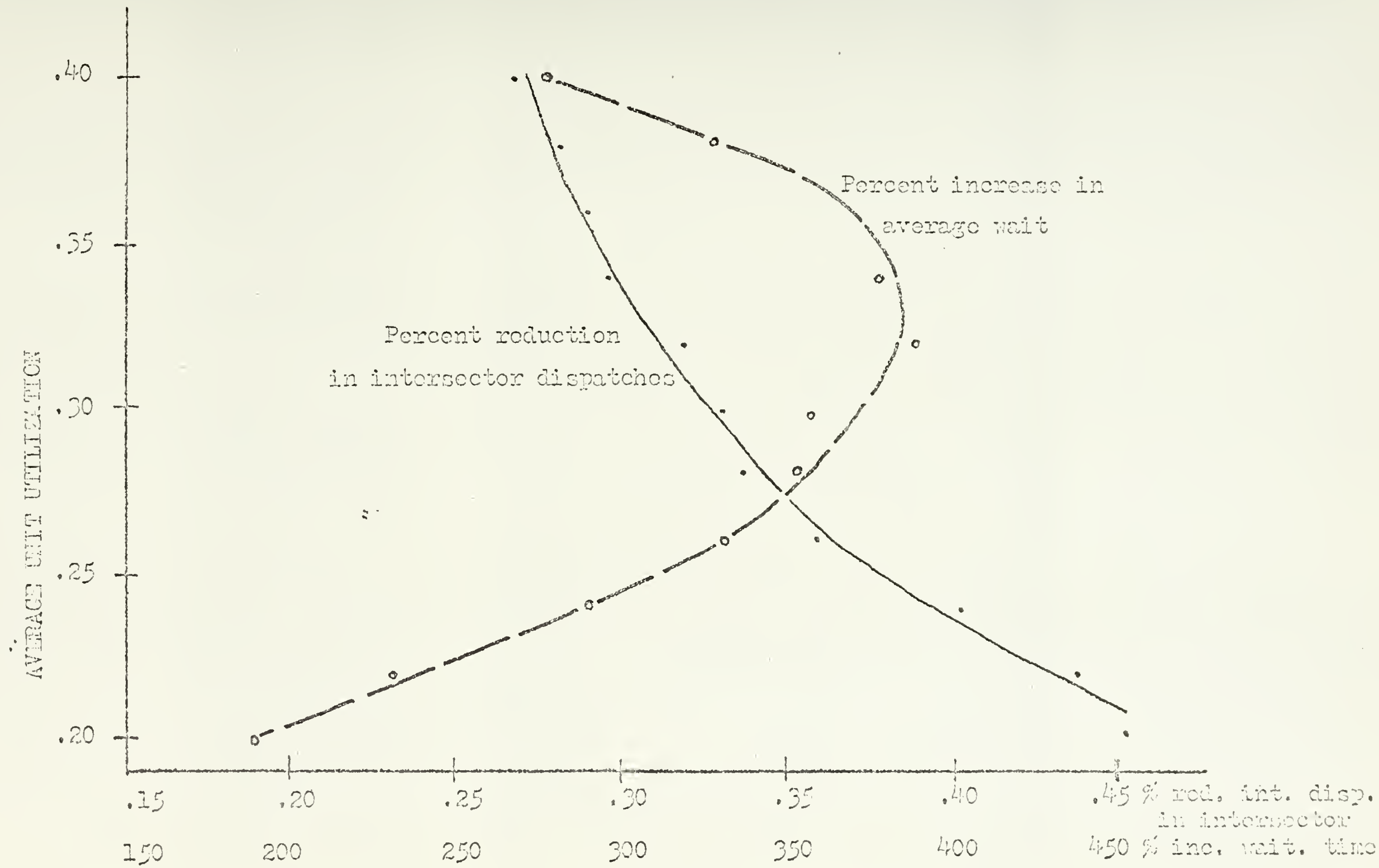


FIGURE 20: PERCENT VARIATION IN PERFORMANCE MEASURES
PRIORITY TWO CALLS; NO RESERVE UNITS



that arrival rates of calls for service in each priority class are uniform over the area. This is primarily because any computer-aided dispatch system sophisticated enough to consider such deployment policies as adaptive dispatching would most likely have as a foundation a design of patrol sectors which provided for the minimization of travel times and the balancing of unit workloads.

The simulation model ignored the effects of travel time in computing the average wait in queue, since the particular choice of atoms in each sector would always make the sector unit the "closest" car by the center-of-mass strategy used. Larson[43] notes that the actual closest car on a point-to-point basis could be in several adjacent sectors in the more general case. Overall, however, expected travel times can greatly increase due to intersector dispatching. Hence, the significant reductions in intersector dispatching caused by the adaptive dispatching strategy would also tend to decrease the expected travel time to an incident. For this reason, the absolute increases in average waiting times generated by the model can be viewed as upper bound statistics.

As noted earlier, the particular service time distribution used was such that two ranges existed wherein t_j'' satisfied the adaptive dispatch criterion with (P,δ) equal to $(.50, 15)$. In other words, if unit j had just begun service when an adaptive dispatch situation occurred, t_j would be such that the criterion would be satisfied. However, if unit j had been busy between 9 and 74 minutes when the situation occurred, the adaptive dispatch criterion would __not__ be satisfied! For demonstration purposes, consider the service time

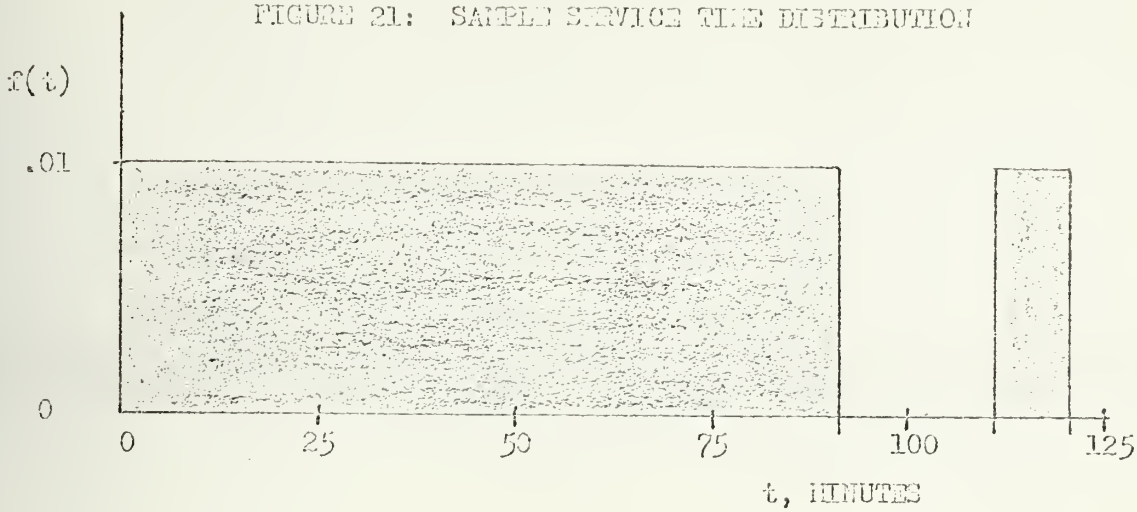
distribution given in Figure 21. Note that for service times t_j between 70 and 80 minutes, the probability that unit j will complete service in the next 15 minutes is equal to or greater than .50. However, for values of t_j between 80 amd 90 minutes, the probability of completing service in $(t_j + 15)$ minutes approaches zero as t_j approaches 90 minutes. Then, for values of t_j above 100 minutes, the probability of completing service in the next 15 minutes again exceeds .50.

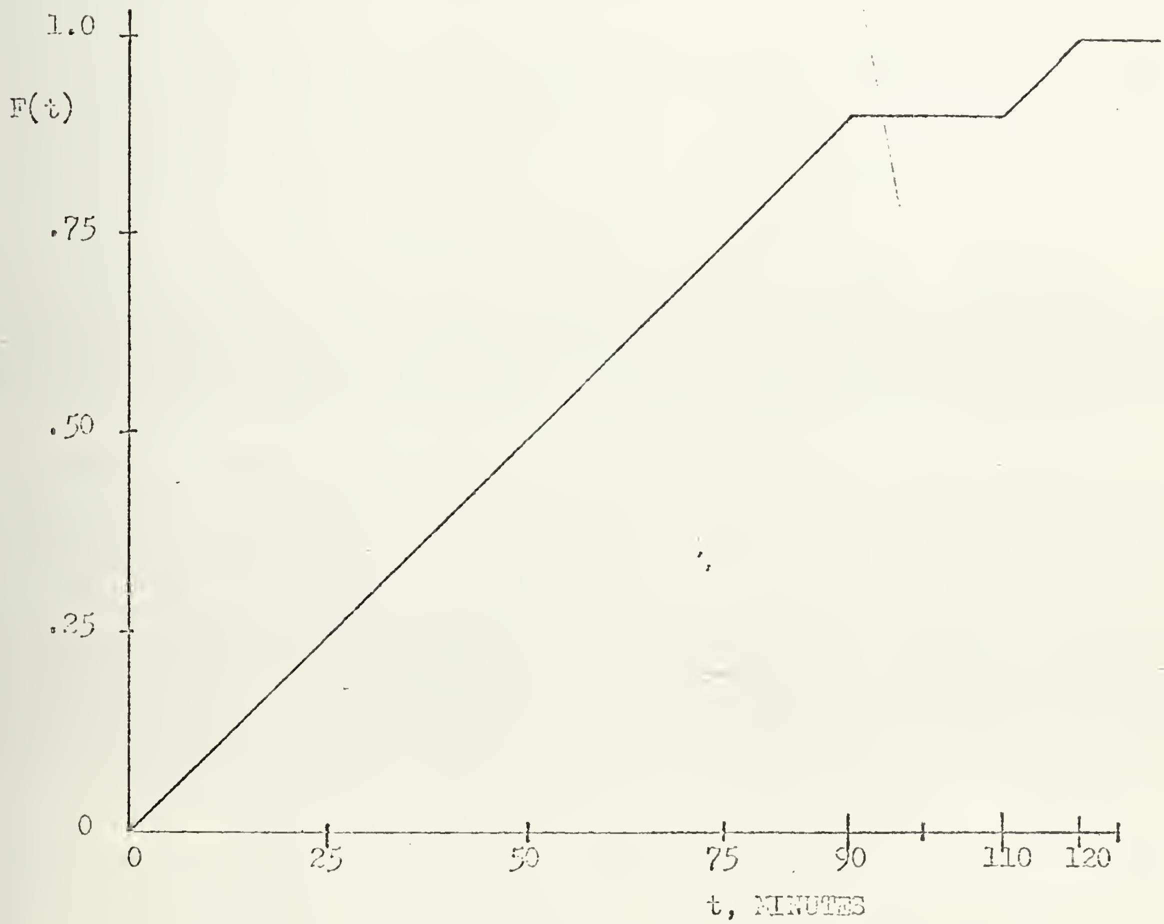
A similar reasoning applies to the service distribution used in the model. Although further research would be necessary to prove the contention that the high maximum waiting times incurred by some callers in the simulation resulted from adaptive dispatches assigned when t_j fell in the range (0, 9), that possibility does seem reasonable. An easy way to check this would be to rerun the simulation, but disallowing adaptive dispatching when t_j was less than 74 minutes.

While there is no reason to believe that the service time distribution of one city should vary significantly from any other, it is interesting to consider how the adaptive dispatching strategy could be changed if the maximum service time were larger than that employed in the model. The obvious extention would be, to monitor the length of time any stacked call waited in queue, assigning it to some other free unit should the waiting time exceed some specified limit. Although such a strategy could have been used in this model, the simulation results do not indicate that any significant gains could be made when the maximum service time was as low as 120 minutes.

Finally, there is no reason to believe that significant tail effects were produced on the waiting time distribution by adaptive dispatching.

FIGURE 21: SAMPLE SERVICE TIME DISTRIBUTION





While it is true that the maximum waiting time increased in some cases by over 100 minutes, the probability of these occurrences remained small. For example, consider an increase in average wait of 2 minutes experienced with a sample of 400 calls. This increase in average wait could conceivably be produced if only 2.5% of the 400 calls waited an extra 80 minutes under an adaptive dispatching strategy. Social implications of such long waits for even 2.5% of the callers, however, could be significant, and should be considered when evaluating such strategies.

5.5 Some Advantages and Disadvantages of Adaptive Dispatching

Besides the obvious benefits of adaptive dispatching in terms of decreasing the amount of intersector dispatching and providing for the partial management of queues, several other advantages can be experienced from implementing this deployment strategy. Most noteworthy is the ability of such "intelligent" dispatch strategies, as discussed in Chapter IV, to help standardize the dispatch decision process. Furthermore, the reduction of intersector dispatching has beneficial side-effects. First of all, the decrease in travel distances to incidents would tend to reduce the occurrence of long, fast runs through crowded city streets, enhancing the personal safety of both the patrolman and the public. Second, the dispatcher would gain some limited, but useful knowledge about the estimated location of each patrol unit, since the units will remain within their sector boundaries a greater percentage of the time.

Lastly, the results of the simulation would indicate that sizable

gains can be realized in terms of queue management routines for the more efficient scheduling of patrol force duties if several priority classifications are used. The adaptive dispatch criterion can heavily favor the stacking of low priority calls by decreasing P_k and/or increasing δ_{jk} for successively higher k. While lengthy waiting times can be expected when more than one call is stacked at any time on a particular unit, these waits might be considered acceptable for certain types of calls in order to benefit from the resultant reduction in the amount of intersector dispatching.

Some of the disadvantages to adaptive dispatching could be significant. A careful study should be made of the effects of stacking calls on the inability of patrol units to complete service on assigned calls prior to the end of their tour of duty. The occurrence of these situations was slight in the simulation runs made by this author. Stacking during these runs was disallowed in cases where an adaptive dispatch situation occurred during the segment of time commencing 1.2 times $(\delta_{jk} + E(t_s))$, where $E(t_s)$ is the expected length of service. This appeared to be an effective means for reducing the instance of patrol unit "carry-over" at the end of a tour.

The long waiting times experienced by some low priority customers can be a decided disadvantage, particularly if an adjacent sector patrol car is observed on preventive patrol while a caller is waiting for service by his own sector unit. These situations should be very infrequent, however, since they normally occur only on sector boundaries.

One last disadvantage of adaptive dispatching is the fact that the control placed on the scheduling of police service might tend to cause

unbalanced patrol unit workloads, requiring the re-design of sector boundaries if a police department was interested in maintaining the former balanced workload conditions. This effect is purely speculation, however, and further research is needed to establish that adaptive dispatching and similar strategies can cause this situation.

5.6 Summary and Further Research

A deployment strategy termed adaptive dispatching was presented which regulates the stacking of low priority calls for eventual service by the patrol unit in whose sector the incident is located. The decision to stack a call was based on service time data of the unit involved, and information concerning the existing queues of calls.

Simulation techniques were employed to study the effects of adaptive dispatching on waiting times in queue and on the amount of intersector dispatching. The results of the simulation indicated that for average unit utilizations between 20% and 40%, the average wait in queue was increased by no more than 3.5 minutes when adaptive dispatching was used. Reductions in the percent of intersector dispatching to less than half the utilization factor could be obtained from adaptive dispatching with minimal effects on average waiting times.

The strategy of reserving a fixed number of patrol units at all times for the service of high priority calls reduced the level of adaptive dispatching as expected, but the arrival rate of high priority calls was so low that the overall effects of this strategy in improving emergency service were negligible, indicating that at most one patrol

unit should be reserved for such use.

The particular model used negated travel time effects, but the decrease in intersector dispatches caused by adaptive dispatching would imply that the absolute increases in average waiting times generated could be considered maximum values. The increase in the maximum wait experienced by any customer was seen to be potentially large, but these effects could be decreased by a more careful study of the service time distribution and the choice of parameters (P_k, δ_{jk}).

5.6.1 Further Research

First on the list of items for further research indicated by this study is an examination of the consistency of adaptive dispatching and similar deployment strategies with police departmental policies and goals. While the dispatch decision process itself deserves much attention, the most immediate issue of importance is the development of effective methods for managing queues of calls for service which balance caller waiting times against the efficient scheduling of patrol force assignments to balance workloads over each tour of duty. This area includes the examination of changes in the adaptive dispatch algorithm, such as searching existing queues for calls in the sector of an available patrol unit, regardless of order in the queue, and alterations involving an increased number or priority classifications.

Finally, the effects of travel times on total response should be studied in more detail under the adaptive dispatching strategy. More importantly, the statistics realized with different service time distributions, particularly from one priority class to another, need to be determined.

CHAPTER VI

POLICIES AND IMPLICATIONS

6.1 Introduction

The previous chapters have largely ignored the topics of CAD system implementation and maintenance, cost considerations, and the social impact of the advanced technology within police departments. These issues are important to all computer-aided dispatch systems, not just "intelligent" CAD designs. Hence, this chapter addresses the above subjects from the framework of general CAD systems. The chapter concludes with a brief forecast of the future of computer-aided dispatch technology.

6.2 Ensuring Success of a CAD System

There are four factors which are crucial to the success of any computer-aided dispatch system. These are: (1) facilities, (2) training, (3) personnel staffing, and (4) in-house technical support. Computer-aided dispatching is an unstructured[44] computer application. It often requires a new set of procedures within the department. The failure of the Cleveland CAD system and the success of the systems in Oakland, San Diego, Las Vegas, and elsewhere have indicated that a complete break with the "old way" of doing police business, specifically including a change of facilities, must be accomplished to ensure system acceptance.

Installing new equipment in a communications room identified with manual dispatch procedures and former job roles, as was tried in Cleveland, can have disastrous effects.

Training in new procedures is, without saying, an obvious part of any type of technological advance. It is an area of design, however, which is always assumed necessary, yet rarely properly executed. With police CAD systems, the personnel which are chosen for training is also an important consideration. Command and Control Center duty has traditionally been considered a recognition of the inability of a man to serve in the field. It is thus perhaps the least desirous of all police assignments. Few volunteers are ever found in Control; alcoholics, those unfit physically or mentally for arduous field work, and the incompetent are not rare.[45] The implications of CAD technology on manpower improvements within the police Command and Control Center are significant. The personnel training necessitated by the new technology and the prestige of operating the system could very well lead to a change in the attitudes of policemen toward working as complaint operators and dispatchers. Most departments have in fact avidly recruited better personnel to operate their new CAD system. While no data exist to support the contention that the allocation of police service will become less discriminatory when a "better" grade of patrolman is trained for complaint operator duties, that hypothesis does at least appear reasonable.

Finally, and perhaps most importantly, it is vital that each police department maintain an in-house technical capability to develop new CAD software, to provide refresher training, to analyze system statistical outputs, and to interface where necessary with city Data Processing

Departments. Without such a capability, a computer-aided dispatch system, particularly an intelligent one, with its complicated dispatch algorithms based on possibly changing departmental policies, can quickly become out-dated, and fall into full or, more likely, partial disuse.

6.3 Cost-effectiveness Considerations

The gains possible with CAD technology are unfortunately being wasted in many circumstances through system design which is insensitive to actual police operations. It is vital that systems engineers become thoroughly familiar with a department's operational procedures prior to designing a CAD package. Besides uncovering police operating procedures which might harmfully effect CAD system performance, it is important that the departmental deployment policies are thoroughly appreciated prior to system design. The failure of the ADAM system in Los Angeles can be directly attributed to an inconsistency between ADAM's design around minimizing response time, and Los Angeles' patrol unit deployment in a Team Policing manner, which sacrifices optimal response time for an increased neighborhood identity.[46]

Present computer-aided dispatch system designs demonstrate an attention to costly hardware which is greatly unbalanced in comparison to software developments. For instance, many CAD terminals contain expensive specialized function keyboards, yet the complete system can only catalog data. While upward compatibility of system equipment must be considered in order to meet future demands, more care should be exercised in the development of system design criteria. The questionable

budgetary benefits of the Huntington Beach CAD System discussed in Chapter II immediately come to mind in this regard. Total command and control system design must be considered when evaluating the cost-effectiveness of new technology. As mentioned in Chapter II, for instance, the purchase of mobile digital communications equipment is a logical first step in overall system design, as many command and control problems center on saturated police radio frequencies.

A good example of ill-spent finances is in the current vogue of automatic vehicle monitoring (AVM) systems. Present AVM systems cost from $1500 to over $6000 per vehicle for design, implementation, and operating costs, exclusive of the expense of necessary computer and peripheral equipment.[47] These costs are perhaps justified if the purposes for installing the car locator system were the enhancement of officer safety and the administrative surveillance of patrol units. Results of the survey described in Chapter III, however, indicated that the AVM system tactical advantages in reducing response times was the overwhelming concern of urban police officials. But Larson[48] has shown that a perfect resolution car locator can improve over the response of a strict-center-of-mass dispatching strategy by less than twenty percent, while a modified-center-of-mass strategy can produce an improvement of about ten percent over strict-center-of-mass dispatching, and can be accomplished with only negligible CAD software expense!

One city which has recognized the cost-benefit relationship of automatic vehicle monitoring systems has instead instituted a system wherein each patrol sector is divided into quadrants, with each quadrant identified for the patrolman by different color paints on lampposts.

When moving from one quadrant to another, the officer communicates his change in location to the computer-aided dispatch system via mobile digital transmission. An intelligent CAD system could easily use this information in estimating the "closest" unit to each call for service, and at an insignificant cost compared to any current AVM system.

Vendor pressures and the attractiveness of Law Enforcement Assistance Administration (LEAA) money, combined with a lack of technical expertise within urban police departments continue to be major factors in the purchase of computer systems by police.[49] The LEAA has recently recognized its responsibility to provide guidance to police officials in the evaluation of systems applicability and cost-effectiveness for police operations, and has therefore contracted for the development of a set of planning manuals on equipment of advanced technology such as mobile digital, CAD, and AVM systems. The ultimate responsibility for the purchase of cost-effective systems, however, lies with the police administrator.

6.4 Some Operational Impacts of CAD Technology

The effects of advanced technology on the patterns of practice within urban police departments is profound. As the most sophisticated computer application area for police, computer-aided dispatch systems not unsurprisingly hold widespread implications for the delivery of services and for the roles of police officers and administrators.

While the use of "intelligent" CAD routines such as those mentioned in Chapter IV would provide non-discriminatory decisions concerning call

validity, it is unrealistic to assume that the formalization of these procedures will decrease the informal partitioning of calls and assessment of call validity on behalf of complaint operators, as described below.

The installation of a 911 emergency phone system is a standard practice when instituting computer-aided dispatching. Data collected in New York City indicate that police departments experience a large increase in demand when 911 service commences.[50] Although many of these added calls are of an administrative nature which can be routed to other bureaus, an appreciable number of callers think they require police service. It becomes necessary in such situations to establish formal screening procedures so that the apparent increase in activity can be reduced to a level more in line with patrol vehicle resources. The benefits to the complaint operators in terms of dissonance reduction[51] are great under a formal screening policy. The defense of operator actions gained on behalf of administrators appears to far outweigh the problems encountered when service is refused to clients.

Computer-aided dispatch systems categorize calls for service into a minimum of three priority classes. These are: (1) emergencies, such as crimes in progress, (2) routine police matters, and (3) administrative calls, such as the taking of burglary reports. It is important to distinguish the fact that these priority classifications are devised to aid the dispatcher in organizing calls into queues while awaiting the availability of scarce patrol vehicles. While complaint operators do make some attempt to handle calls within the framework of these formal priority classifications, it is interesting to examine the process by which the

operators actually partition calls into categories.

"Normal" clients[52] -- those who are readily identified as qualifying somehow for a particular police service -- usually are directly fit into one of the established priority classes. "Non-normal" clients are not. The latter can be divided into two groups -- those who receive police service begrudgingly, and those to whom service is refused. There are a number of factors which cause this phenomenon. Racial tensions and biases form an important part of the decision structure for handling calls for service. Ethnicity, particularly in regard to Puerto Ricans and Mexican-Americans, has similar influences. Racial and ethnic identity is established in many ways over the phone, but most easily through accents and call locations. It is not unlikely that if a caller's accent or language is not easily "readable", that person will not receive service. Fear of reprisal for the operator's actions is almost non-existent in such cases.

The location of incidents plays an important part in assessing the call. Certain types of crimes are not considered "normal" for certain areas. For example, a Boys Complaint in an upper- or middle-class neighborhood might indicate that more serious crimes than loitering are imminent. If the operator has knowledge that the incident address is in a ghetto area, he often begins to assess the call on the basis of a set of standards having roots in racial prejudice. Such calls are often not considered "valid", and service is typically rendered reluctantly. The issue of validity encompasses exaggerated reports, false reports, and generally "unbelieved" reports. The latter category pertains to calls which are not given validity due to misconceptions such

as a view of the black American as one who uses the police to mediate petty arguments and to make life miserable for unliked neighbors, among others.

It is important to note that many police clients thoroughly recognize the criteria for allocating service.[53] Exaggerated reports such as falsely stating that weapons are involved in a family dispute, or that a crime is in progress when it actually occurred long ago have been found to be highly successful strategies for client control over the allocation of services. Should the complaint operator perceive the caller as one whose validity is suspect, however, the call is reduced in priority over what the report would otherwise indicate, and stereotypes which the operator harbors are reinforced.

To borrow a documented example[54] of the above phenomenon from another urban service organization, it was recently determined that the probability of a false fire alarm in New York City now exceeds that of the receipt of a legitimate call. A majority of the false alarms are originating from voice boxes, originally installed to decrease the incidence of falsified reports. Fire officials have determined that youngsters in low-income tenement areas issue a significant percentage of these alarms, supplying descriptions which result in the dispatch of at least an engine company and fire company. To combat the millions of dollars lost in responding to false alarms, the Fire Department plans to institute a selective response system, whereby boxes with a high rate of false alarms and low rate of actual fires will be avoided in order to increase the chance of getting to legitimate fires. The result will of course be service which discriminates against the poverty-stricken.

Systems engineers and police decision makers consider the dispatcher to be the crux of the CAD system. Hence, the major thrust of CAD design is to provide the dispatcher with more information; the effect is to limit his discretion and autonomy. Whereas the dispatcher once was able to queue calls according to his own judgement, the computer-aided dispatch system suggests controls on the rationing of service according to waiting times. As the dispatcher does not desire to explain to his supervisor why he continually assigns patrol units to calls for service on other than a first come, first served basis, his normal reaction is to submit to the CAD system's queue management routines. Furthermore, if the CAD design provides for the timely processing of statistics for management information purposes, the upper echelons of the police hierarchy receive data concerning patrol division status and operations of which previously only the dispatcher had knowledge. As Colton[55] noted, the level of control experienced by officials over patrol force resources can be significantly increased by such methods.

Perhaps the most significant effect that CAD technology can have on the delivery of service to the public lies in the potential that such systems have in regard to the standardization of unit assignments among dispatchers, and particularly between dispatcher actions and departmental policies. Computer-aided dispatching makes possible the routinization of complex dispatching criteria such as are involved in strategies for pre-emption and the maintenance of neighborhood identity. Furthermore, the ability to efficiently catalog complaint data certainly decreases the incidence of discretionary management of queues by the dispatcher.

As a final note, the ways in which CAD technology can be circum-

vented are numerous. The informal procedures for the handling of calls by the complaint operator described above is one example. Of critical importance are the ways that the statistics on which computer algorithms are based and performance evaluated are caused to be inaccurate. For example, the practice of patrolmen not reporting back in service immediately after completing a job elongates the service time distribution, and can have disastrous effects on response times. The problem of not knowing the actual status of units has the greatest effect when the CAD system contains "intelligent" algorithms which depend heavily on the number of free units at any time, such as adaptive dispatching, queue management, and the strategy of maintaining reserve units for high priority calls.

Care also must be taken in analyzing 911 emergency phone system statistics such as trunck line utilization and maximum waiting times prior to the answering of calls by complaint operators. Personal observations of situations where an operator will clear all the calls on his board without answering would indicate that care must be taken in the collection of performance statistics. In this case, an increase in arrivals, assuming people would call back, and a decrease in operator response time would result.

The careful study of operational impacts of CAD technology such as those described above should receive a major portion of the design effort of computer-aided dispatch systems. The solution to these types of problems are necessary to ensure the future success of CAD technology.

6.5 The Future of CAD Technology

With the introduction of micro-computer components to CAD systems, the inability to expand software capabilities for "intelligent" computer-aided dispatching will no longer be an issue. It has already become necessary for many police departments to remove themselves from under the wing of their city data processing auspices in order to maintain an effective, real-time capability. An expansion of system hardware to include micro-computers instead of mini-computers will indicate a department's firm commitment to computer technology, and require the break from Data Processing. Furthermore, the expansion of capabilities might finally convince some police departments of the need for in-house technical support.

Systems such as AID[56] which provide co-operative computer-aided dispatching for several small cities or towns at shared costs can be expected to gain prominence in the near future, if only for the resultant ability to reduce mounting paperwork. Digital communications systems, originally purchased for their ability to greatly reduce radio network saturation, will be forerunners of intelligent computer-aided dispatching due to their ability to rapidly receive and transmit data, and their use in updating patrol unit status. Finally, much work needs to be done in regard to CRT display and keyboard design. For instance, it has been observed that typing errors are much more frequent when the complaint operator can follow what is being typed on the CRT display, and certain dispatcher functions are being ignored due to complex display formats and involved call-up procedures.[57] It is vital in this regard that intelligent CAD systems maintain easy to read, uncomplex display formats and simple

operator-computer interfacing procedures.

While the importance of response time to police operations is unquestioned, the current practice of investing huge amounts of local and federal money for small reductions in response time must end. Police departments would do well to utilize intelligent computer-aided dispatch algorithms to routinize their dispatch assignments, and to include departmental deployment policies such as pre-emption and the maintenance of neighborhood identity. Increased computer use by police will shortly indicate to administrators the benefits to response time that can be gained from simple managerial controls on the scheduling of vacations, shift manpower levels, and co-operation with judicial branches concerning the efficient scheduling of police officer appearances in court.

More generally, "intelligent" computer-aided dispatching can be used effectively to incorporate more people-sensitive routines into the current hardware approach to the improvement of police service for the public. While basic issues such as the purpose of police work and who should control police operations are beyond the scope of computer technology, many other concerns such as increasing interpersonal communications are not. Specifically, strategies such as adaptive dispatching can be employed to contribute to the improvement of police-community relations.

6.6 Summary

Guidelines for ensuring the success of any computer-aided dispatch system were presented, most important of which is the development of an in-house technical capability. Such staffing is crucial for the

maintenance of CAD software and the analysis of statistics generated by the system. Without this technical support it is quite likely that CAD systems will fall into disuse.

In order to provide for the cost-effective utilization of computer technology, it was noted that a thorough analysis of a police department's operational procedures is the first step which must be accomplished in the process of design. Furthermore, system capabilities must be carefully evaluated in terms of benefits experienced and alternatives available. In many cases, a minimal expansion of CAD software in an "intelligent" manner can provide advantages which are comparable to those achieved by other costly, complex systems.

Ways in which advanced technology changes the patterns of practice within police departments were examined. It was observed that CAD systems have negligible effect on the discretion which is exercised by complaint operators when assessing incoming calls for service, and that the effects on dispatcher discretion and autonomy can be significant. The issue of circumvention of computer-aided dispatch technology is one which should receive considerable research.

Finally, a forecast of future developments in CAD system technology was presented. A re-examination of the benefits of response time versus those departmental policies such as pre-emption and the maintenance of neighborhood identity was urged. In particular, the use of "intelligent" CAD routines was predicted as a possible means for adapting current hardware approaches to the improvement of police service in a more acceptable manner.

CHAPTER VII

CONCLUSIONS AND FURTHER RESEARCH

7.1 Conclusions

The intent of this paper has been to examine the current level of computer-aided dispatch technology, and to indicate several ways in which CAD Systems can be made more "intelligent" that are in consonance with realistic police operational procedures. The following conclusions can be drawn from this research:

i) Currently operational computer-aided dispatch systems are not being effectively used. Cataloguing of incident data and the monitoring of patrol unit status are the major capabilities of present CAD designs.

ii) While most dispatchers use the "standard" dispatching algorithm, police administrators express an interest in other policies such as pre-emptive dispatch and the maintenance of neighborhood identity. Unfortunately, officials have largely failed to provide formal guidelines for the use of such policies.

iii) While CAD systems are in theory based on efficient patrol resource allocation, few police departments use more than educated guesswork for deploying manpower, and none provide for effective allocation under the common condition of fluctuating manpower resources.

iv) Intelligent computer-aided dispatch of patrol vehicles can effectively be used in current CAD systems for:

a) Reducing delays resulting from manual search of data files.

b) Checking the validity of calls for service.

c) Efficiently allocating patrol resources in a dynamic manner to account for fluctuating manpower levels.

d) Increasing patrol officer safety through improved data flows.

e) Standardizing dispatch assignments among dispatchers and between dispatcher actions and departmental policies.

f) Improving police service by incorporating strategies which, for example, increase neighborhood identity or provide better response to emergency situations.

g) Incorporating complex mathematical models for purposes such as estimating patrol unit location and managing queues of calls for service.

h) Collecting and analyzing statistics which are useful to police administrators.

v) The computational capabilities of CAD systems can be capitalized upon to incorporate strategies such as adaptive dispatching. This particular strategy can effectively be used to greatly decrease the amount of intersector dispatching, with acceptable increases in average waiting times in queue of calls for service. It is significant that the adaptive dispatch criteria can be chosen such that the

percentage of dispatches between sectors would be less than half the average utilization factor of the patrol units, while the average wait in queue would increase by less than five minutes.

vi) A strategy of maintaining a fixed number of free units for response to high priority calls, and thus reducing patrol resources for lower priority calls, causes insignificant effects on average waits in queue for the lower priority calls. The low arrival rate of emergency calls, however, make suspect the usefulness of this strategy.

vii) The success of computer-aided dispatch systems within police departments depends not only on good design, but also on personnel training and staffing, working environment, and most importantly, the development of in-house technical support.

viii) Even the highly routinized procedures for call handling under intelligent computer-aided dispatching have little effect on the informal procedures exercised by the complaint operator for assessing incoming calls for service.

7.2 Further Research

Five major areas for further research are indicated by this paper. These are:

i) A detailed examination of patrol force deployment policies of police administrators such as pre-emptive dispatching, and a study of the integration of all such strategies into a complete dispatching decision process.

ii) An analysis of the advantages and disadvantages of strategies for the handling of calls for police service other than the

first come, first served policy currently in use. It is important that such a study include a thorough examination of the benefits of grouping calls into several priority classifications.

iii) The development of a guide to aid police administrators in planning for the establishment of a command and control system adequate for each department's particular needs, including the integration of digital communications, computer-aided dispatch, management information, automatic vehicle monitoring, and similar systems into a complete package.

iv) The examination of ways in which personnel circumvent advanced technology, and methods for the prevention of undesirable actions in this regard.

v) Finally, a methodology for addressing people-sensitive issues in the improvement of police service within the context of a technological environment needs to be developed.

In summary, the field of computer-aided dispatching design requires an increasing awareness and sensitivity of police operational procedures on the part of systems engineers. Furthermore, only through the combined efforts of police administrators, engineers, and social scientists can a solution to the problems of the provision of adequate, non-discriminatory police service be reached.

FOOTNOTES

1. Wilson, C.W., Police Administration, 1972.

2. Institute for Defense Analyses, President's Commission on Law Enforcement and the Administration of Justice, Task Force Report: Science and Technology, 1967

3. Colton, K.W., "Computers and the Police Revisited: A Second Look at the Experiences of Police Departments in Implementing New Information Technology", Urban Data Service, Vol. 6 No. 11, November, 1974.

4. Ibid.

5. Ibid.

6. Larson, R.C., Operational Study of the Police Response System, Technical Report No. 26, 1967.

7. Ibid.

8. A more complete description of geographic base files is given in Chapter IV.

9. The geographic base file contains X - Y coordinates of each location in the city for future use in an automatic vehicle monitoring system..

10. Huntington Beach Police Department, Computer-Aided Dispatching System: Phase I, 1974.

11. Data collected by the police department, based on the 1973 level of calls for service. Values given are averages.

12. Larson, R.C., Urban Police Patrol Analysis, 1972.

13. See, for example, Larson, R.C., A Hypercube Queuing Model for Facility Location and Redistricting in Urban Emergency Services, 1973, and Jarvis, J.P., Optimal Dispatch Policies for Urban Server Systems, Technical Report 02-73, 1973

14. Colton, op. sit.

15. Supervisors are tasked with, among other things, follow-up duties on many calls for service which require their presence at locations throughout their district during any one tour.

16. Mitre Corporation, Urban Field Tests of Four Vehicle Location Techniques, 1973.

17. Johns, J.H. and Oswald, L.J., Operating Characteristics and Performance Measures of the Patrol and Communications Divisions of the Newark Police Department, 1974

18. "Wild" and "umbrella" cars are normally assigned patrol duties over several sectors within a district. "Cover cars" are normally assigned two patrol sectors, and are the first preferred back-up unit for the patrol units regularly assigned to those sectors.

19. Squadrols and vans are normally used for both patrol duties and the transportation of prisoners.

20. Auxiliary police are civilians with some minimal police training that are used for special duties such as at parades and other special functions.

21. For a complete discussion of pre-emptive dispatching and a methodology for its implementation, see Oswald, L.J., Preemption - A Viable Strategy?, Masters thesis, MIT, 1975.

22. Larson, op. sit.

23. Ibid.

24. Johns, Oswald, op. sit.

25. Larson, op. sit.

26. Colton, op. sit.

27. Mitre Corporation, op. sit.

28. See, for example, Larson, R.C., A Hypercube Queuing Model for Facility Location and Redistricting in Urban Emergency Services, 1973, Jarvis, op. sit., and Campbell, G.L., A Spatially Distributed Queuing Model for Police Patrol Sector Design, 1972.

29. Larson, op. sit., and Urban Police Patrol Analysis, 1972.

30. Jarvis, op. sit.

31. Larson, op. sit.

32. Larson, R.C., "Improving the Effectiveness of New York City's 911", in Drake, A.W., Keeney, R.L. and Morse, P.M., eds., Analysis of Public Systems, 1972.

33. Sherman, L.W., Milton, C.H. and Kelly, T.V., Team Policing, 1973.

34. See, for example, Drake, A.W., Fundamentals of Applied Probability Theory, 1967.

35. See Johns and Oswald, op. sit., and Larson, R.C., Urban Police Patrol Analysis, 1972.

36. A patrol unit assigned to a sector near the middle of its district will be a prime candidate for intersector dispatches thus increasing its workload above that of its own sector.

37. Johns and Oswald, op. sit.

38. Larson, op. sit.

39. Johns and Oswald, op. sit.

40. Johns and Oswald, op. sit., and Rubinstein, J., City Police, 1973.

41. Cox, D.R., and Smith, W.L., Queues, John Wiley & Sons, Inc., New York, 1961.

42. Larson, op. sit., demonstrates that for the general case, the percent of intersector dispatches is equal to or greater than the utilization factor.

43. Larson, op. sit.

44. Colton, op. sit.

45. Rubinstein, op. sit.

46. Colton, op. sit.

47. Mitre Corporation, op. sit., and Montclair Police Department, Vehicle Location and Status Reporting System (LOCATES), 1974.

48. Larson, op. sit.

49. Colton, op. sit.

50. Larson, R.C., "Improving the Effectiveness of New York City's 911", in Drake, A.W., Keeney, R.L. and Morse, P.M., eds., Analysis of Public Systems, 1972.

51. Festinger, L., A Theory of Cognitive Dissonance, 1957.

52. Sudnow, D., "Normal Crimes: Sociological Features of the Penal Code in a Public Defender's Office", Social Problems, 1965.

53. Rubinstein, op. cit., Westley, W.A., Violence and the Police, 1970, and Wilson, J.Q., Varieties of Police Behavior, 1969.

54. Raab, S., "False Alarms Up by 36% Now Exceed Valid Calls", New York Times, Thursday, July 24, 1975.

55. Colton, op. cit.

56. Carrol, A.B., et al, Computer Aided Dispatching for Law Enforcement Agencies, 1974.

57. This information was received by the author from Robert Sohn of the Jet Propulsion Laboratory, Pasadena, California.

58. Larson, R.C., Urban Police Patrol Analysis, 1972.

59. See, for example, Howard, R.A., Dynamic Programming and Markov Processes, 1960.

60. Cox, D.R. and Miller, H.D., The Theory of Stochastic Processes, John Wiley and Sons, Inc., New York, 1965.

BIBLIOGRAPHY

1. Anonymous, untitled, SELECT System description, Seattle Police Department, Seattle, Washington, 1975.

2. Bartlett, M.S., An Introduction to Stochastic Processes, Cambridge University Press, Cambridge, G. Britain, 1956

3. Bordua, D.J., The Police: Six Sociological Essays, John Wiley and Sons, Inc., New York, 1967.

4. Broadbent, S.R. and Kendall, D.G., "The Random Walk of Trichostrongylus Retortaeformis", Biometrics, Vol. 9, 1953.

5. Campbell, G.L., A Spatially Distributed Queuing Model for Police Patrol Sector Design, Technical Report No. 75, MIT Operations Research Center, Cambridge, Massachusetts, 1972.

6. Carrol, A.B., et al, Computer Aided Dispatching for Law Enforcement Agencies, Community Technology, Champaign, Illinois, 1974.

7. Clawson, C. and Chang, S., Analysis of the Patrol-Dispatch Operation, Seattle Police Department, Seattle, Washington, 1975.

8. Colton, K.W., "Computers and the Police Revisited: A Second Look at the Experiences of Police Departments in Implementing New Information Technology", Urban Data Service, Vol. 6, No. 11, November, 1974.

9. Drake, A.W., Fundamentals of Applied Probability Theory, McGraw-Hill Book Company, New York, 1967.

10. Drake, A.W., Keeney, R.L. and Morse, P.M., Analysis of Public Systems, MIT Press, Cambridge, Massachusetts, 1972.

11. Festinger, L., A Theory of Cognitive Dissonance, Stanford University Press, Stanford, California, 1957.

12. Hauser, N., Gordon, G. and Surkis, J., Computer Simulation of a Police Emergency Response System, Polytechnic Institute of Brooklyn, New York, 1969.

13. Howard, R.A., Dynamic Programming and Markov Processes, MIT Press, Cambridge, Massachusetts, 1960.

14. Huntington Beach Police Department, Computer-Aided Dispatching System: Phase I, 1974, and Phase II, 1975, Huntington Beach, California.

15. Institute for Defense Analyses, President's Commission on Law Enforcement and the Administration of Justice, Task Force Report: Science and Technology, U.S. Government Printing Office, Washington, D.C., 1967.

16. Ito, K. and McKean, H.P. Jr., Diffusion Processes and Their Simple Paths, Springer-Verlag, New York, 1974.

17. Jarvis, J.P., Optimal Dispatch Policies for Urban Server Systems, Technical Report 02-73, MIT Operations Research Center, Cambridge, Massachusetts, 1973.

18. Jet Propulsion Laboratory, Emergency Command Communications System (ECCS): System Operations and Performance Requirements, California Institute of Technology, Pasadena, California, 1975.

19. Johns, J.H. and Oswald, L.J., Operating Characteristics and Performance Measures of the Patrol and Communications Divisions of the Newark Police Department, unpublished paper, 1974.

20. Lambert, J.R., Crime, Police, and Race Relations, Oxford University Press, New York, 1970.

21. Larson, R.C., A Hypercube Queuing Model for Facility Location and Redistricting in Urban Emergency Services, New York City Rand Institute, New York, 1973.

22. Larson, R.C., Models for the Allocation of Urban Police Patrol Forces, Technical Report No. 44, MIT Operations Research Center, Cambridge, Massachusetts, 1969.

23. Larson, R.C., Operational Study of the Police Response System, Technical Report No. 26, MIT Operations Research Center, Cambridge, Massachusetts, 1967.

24. Larson, R.C., Urban Police Patrol Analysis, MIT Press, Cambridge, Massachusetts, 1972.

25. Lass, H., Elements of Pure and Applied Mathematics, McGraw-Hill Book Company, New York, 1957.

26. Mitre Corporation, Urban Field Tests of Four Vehicle Location Techniques, April, 1973.

27. Montclair Police Department, Vehicle Location and Status Reporting System (LOCATES), Montclair, California, 1974.

28. Murray, W.S. and Scales, W.C., Overview of Automatic Vehicle Monitoring Systems, Mitre Corporation, National Technical Information Service, U.S. Department of Commerce, No. PB-773509, 1973.

29. National Bureau of Standards, Tables of the Bivariate Normal Distribution Function and Related Functions, Applied Mathematics Series, No. 50, U.S. Department of Commerce, Washington, D.C. 1959.

30. Rubinstein, J., City Police, Farrar, Straus, and Giroux, New York, 1973.

31. Sherman, L.W., Milton, C.H. and Kelly, T.V., Team Policing, Police Foundation, Washington, D.C., 1973

32. Sohn, R.L., et al, Application of Mobile Digital Communications in Law Enforcement - An Introductory Planning Guide, National Criminal Justice Information and Statistics Service, U.S. Department of Justice, Washington, D.C. 1975.

33. Sudnow, D., "Normal Crimes: Sociological Features of the Penal Code in a Public Defender's Office", Social Problems, Vol.12, No. 3, Winter, 1965.

34. Westley, W.A., Violence and the Police, MIT Press, Cambridge, Massachusetts, 1970.

35. Wilson, J.Q., Varieties of Police Behavior, Harvard University Press, Cambridge, Massachusetts, 1969

36. Wilson, O.W., Police Administration, McGraw-Hill Book Company, New York, 1972.

APPENDIX 1

SURVEY QUESTIONNAIRE

Department ____________________________

Name of Respondant ____________________ Position ______________________

Phone ___________________

Please amplify on the reverse side whenever possible.

1. How often does your department update sector (beat) patrol boundaries?

   _______________ Less than six months.

   _______________ Annually.

   _______________ Less often than annually.

2. How are sector boundaries determined?

   _______________ By educated guess from trends.

   _______________ By hazard formulas (the method presented by O.W. in Police Administration).

   _______________ Other. Specify. ____________________________

3. Is your department considering the installation of an automatic vehicle monitoring (AVM) system?

   _____ No. _____ Yes. If yes, what type? _____ Dead Reckoning.

   _____ Proximity detector (e.g. signpost).

   _____ Radio frequency trilateration.

   _____ Other. ______________

4. What do you consider to be the most important feature of an AVM system?

5. What criteria do your dispatchers use for assigning units to calls for service? (e.g. Car assigned to sector of call; otherwise, closest free unit; if all units are busy, first free unit.)

6. What factors do you take into consideration when dispatching a unit outside its own sector (intersector dispatching) ?

7. In your communications center, how many priority classifications are used for handling incoming calls?

_______ All calls are treated with equal priority.

_______ Two or three (e.g. Emergency and Routine).

_______ More than three.

8. When a high priority call arrives, often the closest patrol unit can be busy on a lower priority call. Does your dispatching process provide for preemption (the interruption of the closest unit from the low priority call) in such cases?

_____ Yes. If yes, how is preemption used? Check as many as apply:

_____ By written directive (describe on reverse side).

_____ At the patrolman's discretion.

_____ At the dispatcher's discretion.

_____ Other. Specify. ______________________________

_____ No. If no, would such a procedure be useful in your city? How do you think the public would react?

9. Does your department have established procedures for the repositioning of patrol units during emergency/disaster conditions?

_____ No. _____ Yes. If yes, please describe.

10. When temporary manpower shortages (sickness, vacations, court appearances) result in unmanned patrol vehicles, how do you cover the affected sectors?

_____ Have supervisor (sargeant/lieutenant) concentrate patrol in the unmanned sector (beat) whenever he is available.

_____ Assign more than one beat to a patrol unit.

_____ Alter sector boundaries so that each patrolling unit has one larger beat.

_____ Other. Specify. ______________________________

11. Do your dispatchers have available a list of each patrol unit's "special" capabilities, such as the officer being bilingual or having advanced training in emergency medical care, or of the equipment available in each patrol car?

_____ Yes. _____ No.

If you did have such a list, what information about the patrol units would you include on it?

_____ Emergency medical training of officer.

_____ Bilingual speech of officer.

_____ Race of officer.

_____ Special weapons in vehicle.

_____ Medical equipment in vehicle.

_____ Other. Specify. ______________________________

12. Is timely information available to supervisors (other than the dispatcher) on the status of the patrol force?

_____ No. _____ Yes. If yes, is it computerized? _____ No. _____ Yes.

If yes, what data is available on a daily or weekly basis?

_____ Manning levels.

_____ Workloads of patrol units.

_____ Workloads of sectors.

_____ Analysis of calls serviced/unserviced.

_____ Other. Specify. ______________________________

13. Does your department have a computer-aided dispatching (CAD) system?

_____ Yes. _____ No. If no, and you are planning to install one, when will it be in operation?

_____ In one year.

_____ Less than three years.

_____ More than three years.

The following questions pertain directly to computer-aided dispatching (CAD) systems. Answer only if your department has one in operation or is currently designing one.

---

1. What company designed the system? ______________________

What company built/installed it? ______________________

2. What address verification capabilities does the system have?

_____ None.

_____ Manually by telephone operator.

_____ Computer corrects some misspellings.

_____ Computer identifies street names which don't exist.

_____ Computer identifies street numbers which don't exist.

_____ Other. Specify. ______________________________

3. What types of units can the system assign to calls for service?

_____ Patrol cars.

_____ Foot patrolmen.

_____ Tactical Force units.

_____ Traffic Division units.

_____ Other. Specify. ______________________________

4. Is a capability for the long-term, strategic allocation of resources available within the CAD system? (e.g. sector design, manning levels).

_____ Yes. _____ No.

5. How many units are suggested by the computer for assignment to each call?

_____ One. _____ Three.

_____ Two. _____ More than three. Specify. _______

6. Is the dispatcher constrained to use the computer's choice for unit assignments?

_____ Yes. _____ No.

7. How does the CAD system update the list of busy and free units?

_____ Input by dispatcher.

_____ Digital devices in cars.

_____ Other. Specify. ____________________

8. List the personnel requirements of your CAD system only:

	Maximum	Normal Shift
Number of telephone operators	_____	_____
Number of dispatchers	_____	_____
Number of supervisors	_____	_____
Other. Specify.		

9. What statistics does the CAD system collect?

_____ None. (If none, go on to question 11).

_____ Workloads of the patrol units.

_____ Sector (beat) workloads.

_____ Intersector dispatching.

_____ Crime patterns by location.

_____ Crime patterns by time of day.

_____ Other, Specify. ____________________

10. How are the statistics listed above used?

_____ Stored on discs or tapes for future reference.

_____ Used to update computer dispatching routines.

_____ Output to a management information system (generated in the form of reports to administrators).

_____ Other. Specify. ____________________

11. A basic CAD system contains a geographic base file of reporting districts and a routine for estimating the best unit for assignment to each call for service. There are numerous additional capabilities of CAD systems, however, which make the dispatching process more "intelligent". Several of these capabilities have already been noted (e.g. automatic vehicle location, address verification, repositioning of patrol units in emergencies, etc.). Indicate all such "intelligent" capabilities of your system which have not already been covered. (e.g. Perhaps your system maintains a hazardous address file, or considers the total time in service of busy patrol units prior to making dispatching assignments):

12. What shortcomings of any nature does your system have which you would like changed? What capabilities would you like to have added?

Thank you for completing this questionnaire. If printed material describing your system in detail is available, it would be greatly appreciated, and will be promptly returned if required. We will be happy to send you a copy of the report summarizing the findings of this survey.

APPENDIX 2

SIMULATION MODEL PARAMETERS

DISPATCH ASSIGNMENT PREFERENCE MATRIX

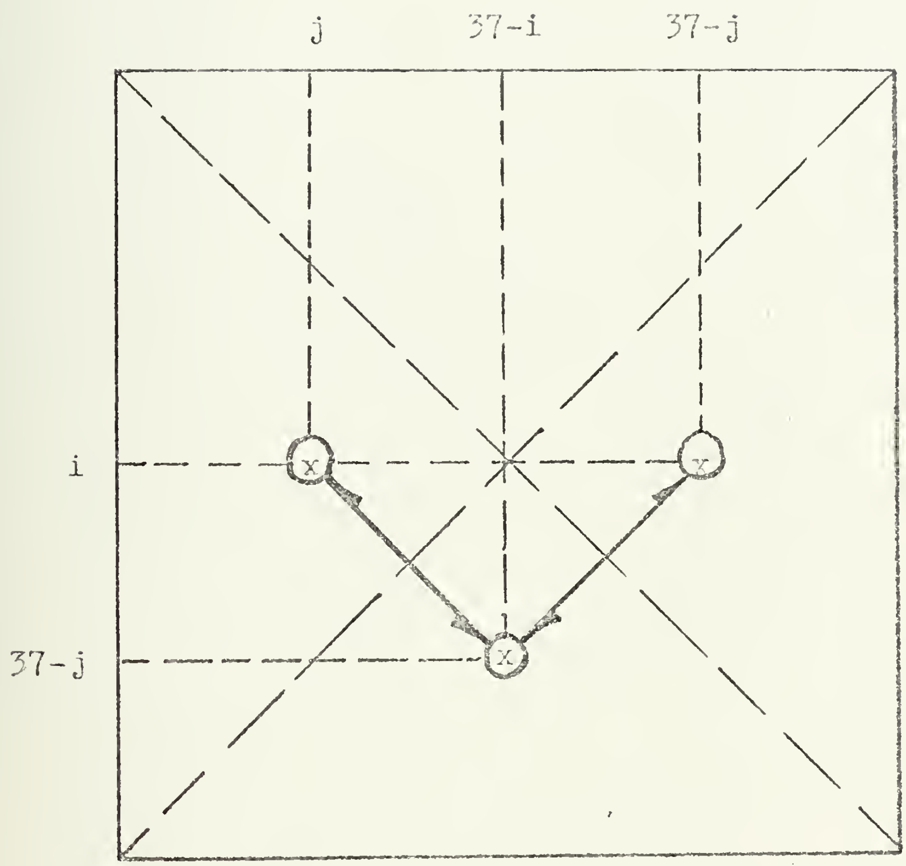
PATROL UNIT

PREFERENCE NUMBER

INCIDENT LOCATION BY ATOM OF ORIGIN	1	2	3	4	5	6	7	8	9
1	1	2	3	5	4	6	7	8	9
2	1	2	3	5	4	7	6	8	9
3	1	3	2	5	6	4	8	7	9
4	1	2	3	5	4	6	7	8	9
5	2	1	4	3	5	7	6	8	9
6	2	4	1	7	3	5	6	8	9
7	2	1	3	5	4	7	6	8	9
8	2	4	5	7	1	3	6	8	9
9	3	1	2	6	5	8	4	7	9
10	3	1	2	5	6	8	4	7	9
11	3	6	1	2	8	5	4	7	9
12	3	6	8	5	1	2	4	7	9
13	4	2	7	5	1	3	9	8	6
14	4	2	7	5	1	3	8	9	6
15	4	2	7	5	1	3	8	9	6
16	4	7	2	5	9	8	1	3	6
17	5	2	3	1	4	6	7	8	9
18	5	4	2	7	1	9	3	8	6
19	5	6	3	8	9	1	7	2	4
20	5	7	9	8	4	6	3	2	1
21	6	3	8	5	1	2	9	7	4
22	6	8	3	5	9	7	2	1	4
23	6	8	3	5	9	7	2	1	4
24	6	8	3	5	9	7	1	2	4
25	7	4	2	5	9	8	6	3	1
26	7	4	9	8	5	2	6	3	1
27	7	9	8	5	4	2	6	3	1
28	7	9	8	4	5	2	6	3	1
29	8	6	3	5	9	7	4	2	1
30	8	9	7	5	6	3	4	2	1
31	8	6	9	7	5	3	4	2	1
32	8	9	6	7	3	5	4	2	1
33	9	7	8	5	4	6	2	3	1
34	9	7	8	5	4	2	6	3	1
35	9	8	7	5	6	3	4	2	1
36	9	8	7	5	6	4	3	2	1

TRAVEL TIME MATRIX

Observe the following symmetry relationships:



Using this information, the reduced travel time matrix becomes:

LOCATION 2

MINUTES / LOCATION 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0																		
2	1	0																	
3	1	1	0																
4	1	1	1	0															
5	2	1	2	1	0														
6	3	2	3	2	1	0													
7	2	1	2	1	1	1	0												
8	3	2	3	2	1	1	1	0											
9	2	2	1	1	2	3	2	3	0										
10	2	2	1	1	2	2	1	2	1	0									
11	3	3	2	2	3	3	2	3	1	1	0								
12	3	3	2	2	3	3	2	2	1	1	1	0							
13	4	3	4	3	2	1	2	1	4	3	4	3	0						
14	5	4	5	4	3	2	3	2	5	4	5	4	1	0					
15	4	3	4	3	2	1	2	1	4	3	4	3	1	1	0				
16	5	4	5	4	3	2	3	2	5	4	5	4	1	1	1	0			
17	2	2	2	1	2	2	1	1	2	1	2	1	2	3	2	3	0		
18	3	2	3	2	2	2	1	1	3	2	3	2	2	2	1	2	1	0	
19	3	3	2	2	3	3	2	2	2	1	2	1	3	3	2	3	1	1	
20	3	3	3	2	3	3	2	2	3	2	3	2	3	3	2	2	1		
21	4	4	3	3	4	4	3	3	2	2	1	1	4	5	4	5			
22	4	4	3	3	4	4	3	3	2	2	1	1	4	4	3				
23	5	5	4	4	5	5	4	4	3	3	2	2	5	5					
24	5	5	4	4	5	5	4	4	3	3	2	2	5						
25	4	3	4	3	2	2	2	1	4	3	4	3							
26	5	4	5	4	3	2	3	2	5	4	5								
27	4	3	4	3	3	3	2	2	4	3									
28	5	4	5	4	3	3	3	2	5										
29	4	4	3	3	4	4	3	3											
30	4	4	3	3	4	4	3												
31	5	5	4	4	5	5													
32	5	5	4	4	5														
33	4	4	4	3															
34	5	4	5																
35	5	5																	
36	5																		

If travel time, $T(j,k)$, between two locations j and k is desired, then the algorithm for reading this value from the reduced matrix is:

i) If $(j + k) \leq 37$, let $m = \max(j,k)$ and $n = \min(j,k)$. Then: $T(j,k) = T(m,n)$.

ii) If $(j + k) > 37$, let $p = \max((37 - j),(37-k))$ and $q = \min((37 - j),(37-k))$. Then: $T(j,k) = T(p,q)$.

APPENDIX 2: MODELS FOR ESTIMATING UNIT LOCATION

This appendix contains an outline of three models which might be used to estimate patrol unit location during certain periods of preventive patrol. The discussion is intended to indicate possibilities for further research.

The situation of concern is the following:

> Patrol unit i has been dispatched to an incident in its own sector, located at position (x_o, y_o). The unit has just reported completion of service at time t_o. The position of unit i is desired at time t_1, a short period after time t_o.

For simplicity, it is assumed that location (x_o, y_o) corresponds to an intersection, and the streets are arranged in a north-south and east-west pattern. Velocities in either direction are the same.

A.2.1 Time - Equidistant Model

Perhaps the simplest location model is one which estimates unit i to be in an area bounded at a distance from position (x_o, y_o) which depends on the time span $(t_1 - t_o)$, and an estimated maximum velocity, V_{max}. Since the area of interest is small, and no other information is used, the probability density function for the location of unit i is assumed to be uniform within the boundaries. Hence:

$$P((x_i, y_i, t_1)|(x_o, y_o, t_o)) = \begin{cases} A^{-1} & \text{if } |x_i - x_o| + |y_i - y_o| \leq (t_1 - t_o)V_{max} \\ 0 & \text{otherwise} \end{cases}$$

where $A = 2(t_1 - t_o)^2 \cdot V^2_{max}$, the total area inside the model boundaries.

Figure 22 depicts the time-equidistant model. While this model has the nice feature of simplicity, it might not yield sufficient accuracy in practice. The choice of V_{max}, the estimated maximum velocity, is critical. An estimated mean or median velocity might prove more desirable. Deviations of street design from the right-angle ideal case can be accounted for by a multiplicative constant,[58] but the assumption that the unit is not restricted to streets might not be consistent with short time intervals of travel after time t_o. Certainly, the assumption that the density function of the unit location is uniform is suspect, even for the small time intervals considered. The model is useful, however, for establishing maximum search areas in the event that patrol unit i is in trouble, with no radio contact.

A.2.2 Diffusion Process Model

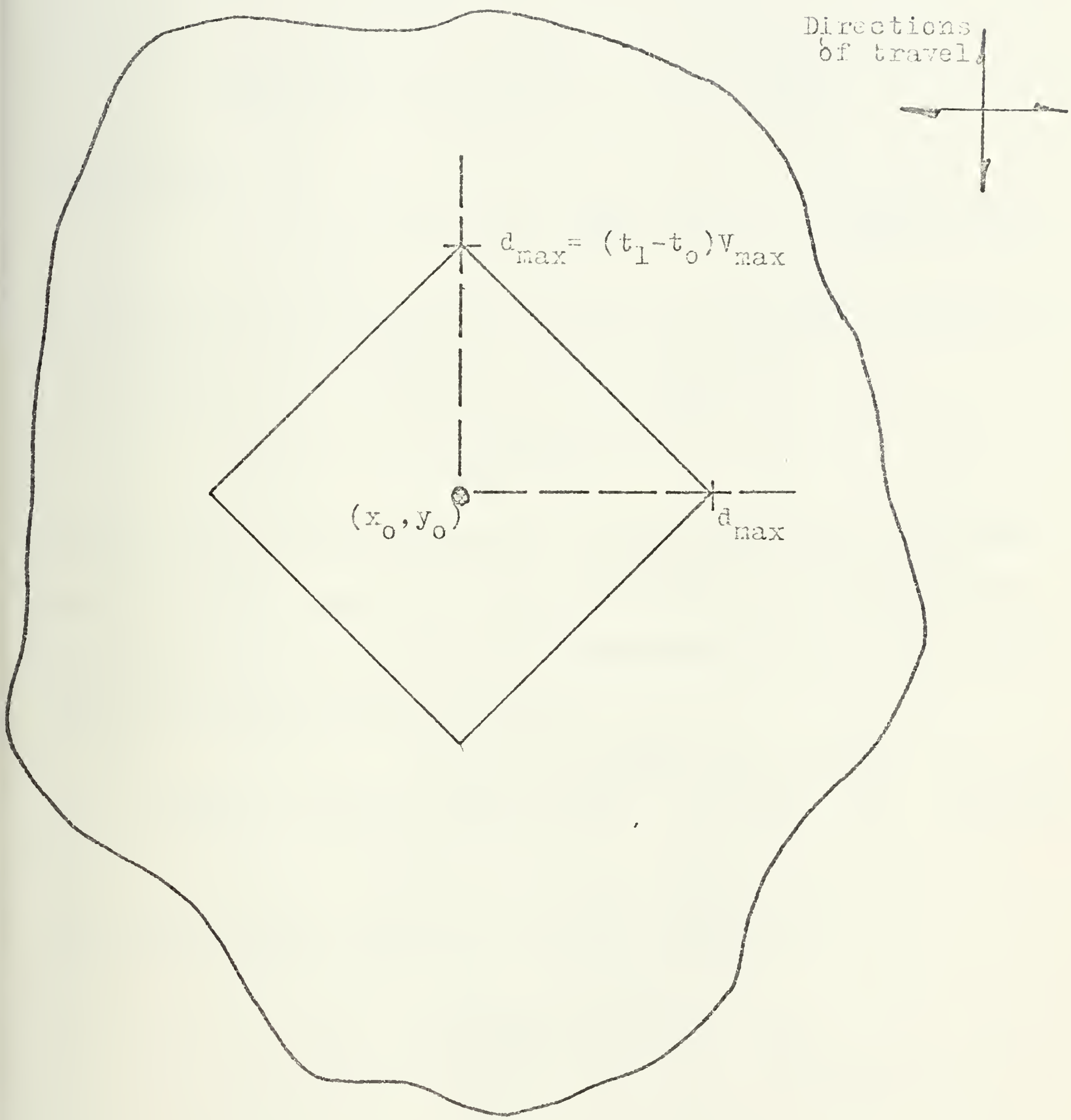
Once again, it is assumed that the patrol unit can occupy any position within its sector. The position of the unit can be viewed as a diffusion process by taking the continuous limit of a simple random walk.[59]

Consider small steps in one-dimensional space of magnitude γ, occurring at small time intervals of length δ. Let the patrol unit start at the origin, x_o, and move a step S to the right or left at each time interval δ. Then:

$$P(S = +\gamma) = p \ , \quad P(S = -\gamma) = q = 1 - p \ ,$$

where each step S is independent of all other steps. The moment generating function of a single step is therefore:

FIGURE 22: THE TIME-EQUIDISTANT MODEL



$$E(e^{-\theta S}) = pe^{-\theta\gamma} + qe^{-\theta\gamma}.$$

Hence: $E(X(t)) = (t/\delta)(2p-1)\gamma$, $V(X(t)) = 4(t/\delta)(p - p^2)\gamma^2$.

Requiring the limiting process to have mean μ and variance σ^2 in unit time, then:

$$\gamma = \sigma\sqrt{\delta}, \quad p = \tfrac{1}{2}\left(1 + \frac{\mu\sqrt{\delta}}{\sigma}\right), \quad q = \tfrac{1}{2}\left(1 - \frac{\mu\sqrt{\delta}}{\sigma}\right).$$

Substituting:

$$E(e^{-\theta X(t)}) = \left(\tfrac{1}{2}\left(1 + \frac{\mu\sqrt{\delta}}{\sigma}\right)e^{-\theta\sigma\sqrt{\delta}} + \tfrac{1}{2}\left(1 - \frac{\mu\sqrt{\delta}}{\sigma}\right)e^{\theta\sigma\sqrt{\delta}}\right)^{t/\delta}.$$

Expanding in powers of δ, taking logarithms, and letting δ approach zero, the cumulant generating function of $X(t)$ is found to be:

$$C(\theta,t) = (-\mu\theta + \tfrac{1}{2}\sigma^2\theta^2)t,$$

which is the generating function of a Gaussian distribution with parameters μt and $\sigma^2 t$. Expanding to the two-dimensional case, the fact that displacement $X(t)$ is independent from displacement $Y(t)$ is used to obtain the joint probability density function:

$$f(x,y) = (2\pi\sigma_x\sigma_y t)^{-1}\exp\left\{-\frac{(x-\mu_x t)^2}{2\sigma_x^2 t} - \frac{(y-\mu_y t)^2}{2\sigma_y^2 t}\right\} \qquad \begin{matrix} x \in (-\infty,\infty) \\ y \in (-\infty,\infty) \end{matrix}$$

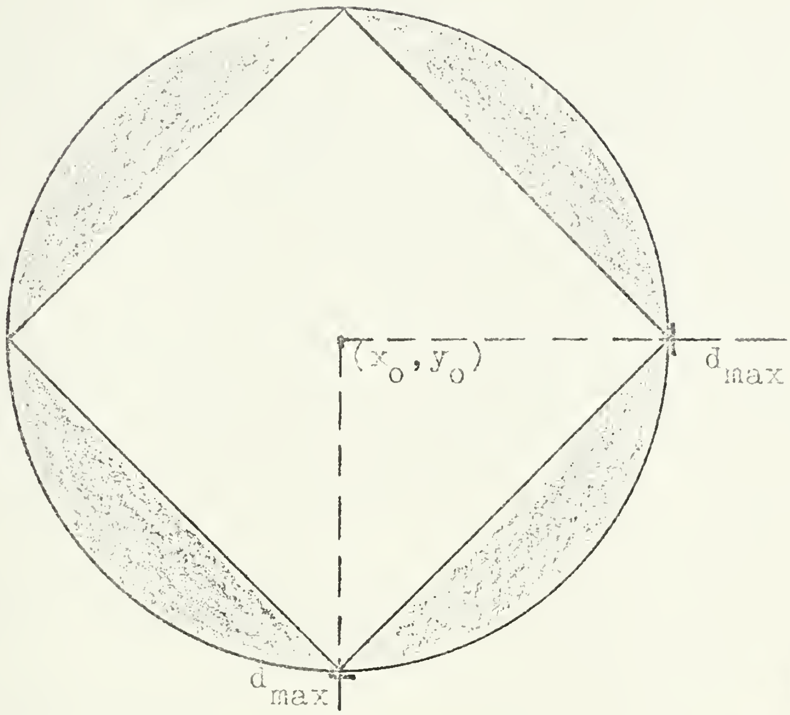
The radial distance, $R(t)$ has the Rayleigh distribution:

$$f(r) = \begin{cases} \dfrac{r}{\sigma^2 t}\, e^{-r^2/2\sigma^2 t} & r \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

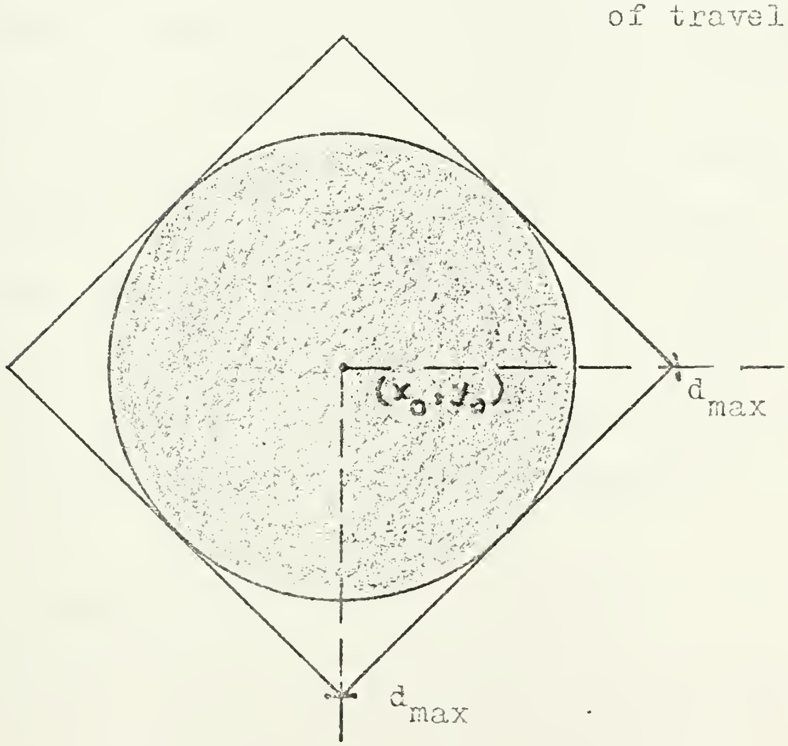
where $R^2(t) = X^2(t) + Y^2(t)$, $X(0) = Y(0) = 0$, and $\sigma_x = \sigma_y = \sigma$.

FIGURE 23: COMPARISON OF TWO LOCATION MODELS

A:



B:



Since it can be assumed that unit i remains in its sector unless dispatched elsewhere, the sector boundary can be treated as a reflecting barrier. A concise treatment of barriers for the univariate case can be found in Cox and Miller.[60] Equations for the bivariate cases are extremely tedious to derive, and are not crucial to this example.

While in practice the quantity σ^2 could be derived from microscopic considerations such as street density, turning probabilities at each intersection, and spatial crime patterns, a reasonable upper bound on σ^2 can be established by ensuring that $P(\sqrt{x^2 + y^2} \leq d_{max}) = 1 - \varepsilon$, where $\varepsilon \leq e^{-8}$. This condition is satisfied if:

$$\sigma \sqrt{t} = \tfrac{1}{4} \cdot d_{max} \text{ ; or, equivalently}$$

$$\sigma^2 = \tfrac{1}{16} \cdot V_{max} \cdot d_{max}$$

Figure 23 depicts a comparison of the diffusion process model with the time-equidistant model. In Figure 23A, the total probability over coordinates (x,y) in the shaded region is .00928 for the diffusion process model. Similarly, the probability over the shaded area in Figure 23B is .98168. Using the diffusion process model, the probability of the unit location being in the "corners" of the time-equidistant model is therefore .00904. It can be easily shown that the probability over these same four areas is .21460 for the uniform distribution.

A.2.3 Random Walk Models

While the diffusion process model represents a continuous time, continuous state Markov process, the location of unit i can also be

approximated by a discrete state, discrete time Markov process, among others. Since these models can become quite complicated, a simple example is chosen for illustrative purposes.

Assume that the sector assigned as the patrol area for unit i is composed of a regular lattice formed by square blocks. Assume also that the unit's position at time t_o is central to its sector, so that boundary constraints can be ignored. Finally, let the unit's velocity be deterministic such that:

$$d = v \cdot \delta t$$

Where: v = velocity of unit i

d = length of one block

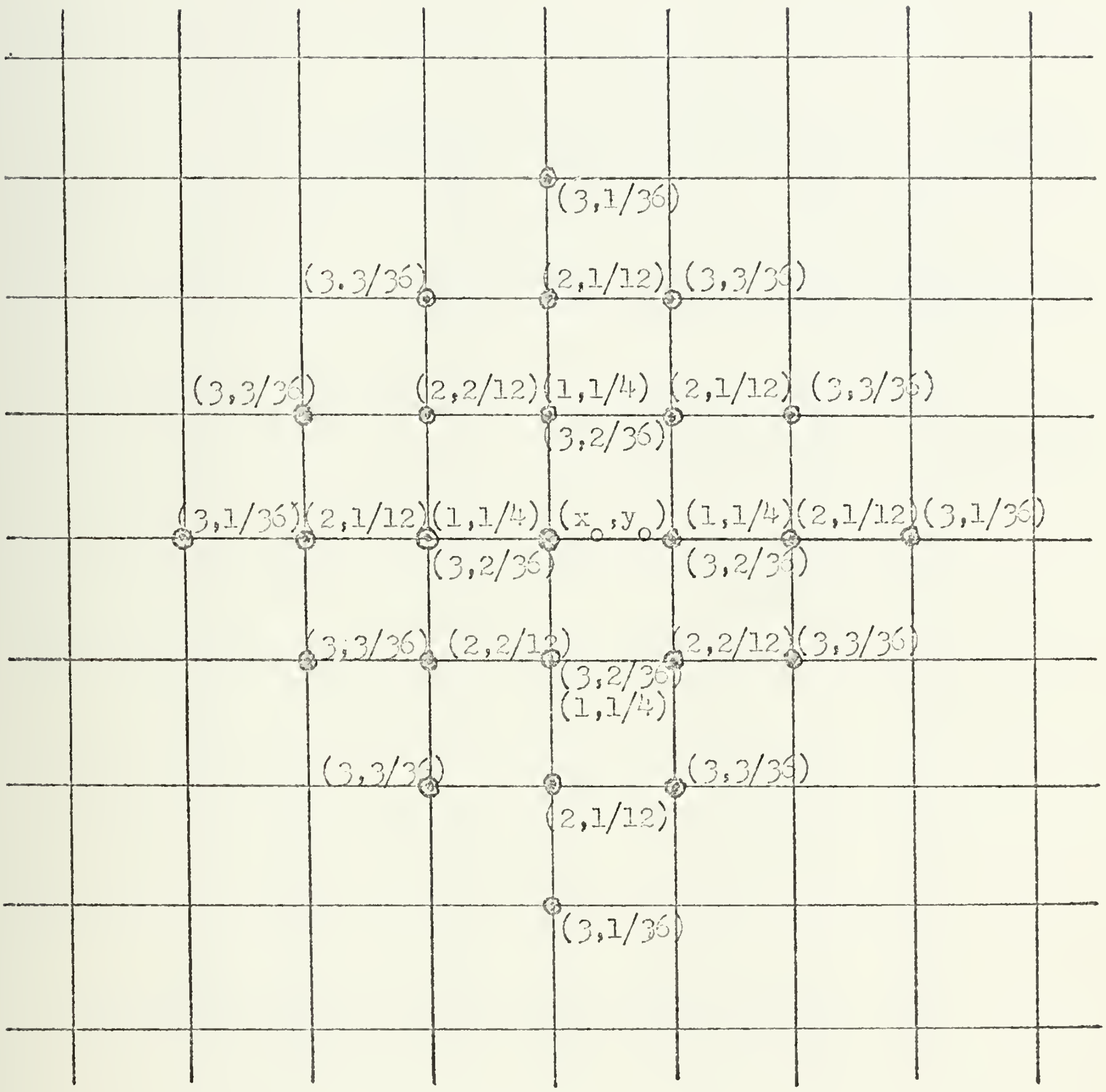
δt = one time interval

Then, the probability of a step at an integer multiple of the interval δt is unity. The states of the system correspond to the intersections in sector i.

If patrol unit i is equally likely to move north, south, east, or west at time $t_o + \delta t$, and thereafter may turn left, right, or continue straight woth equal probability, but may not make a U-turn, then the resulting state occuppancy probabilities are as shown in Figure 24. Figure 25 gives similar results in a case where sector boundary conditions must be imposed.

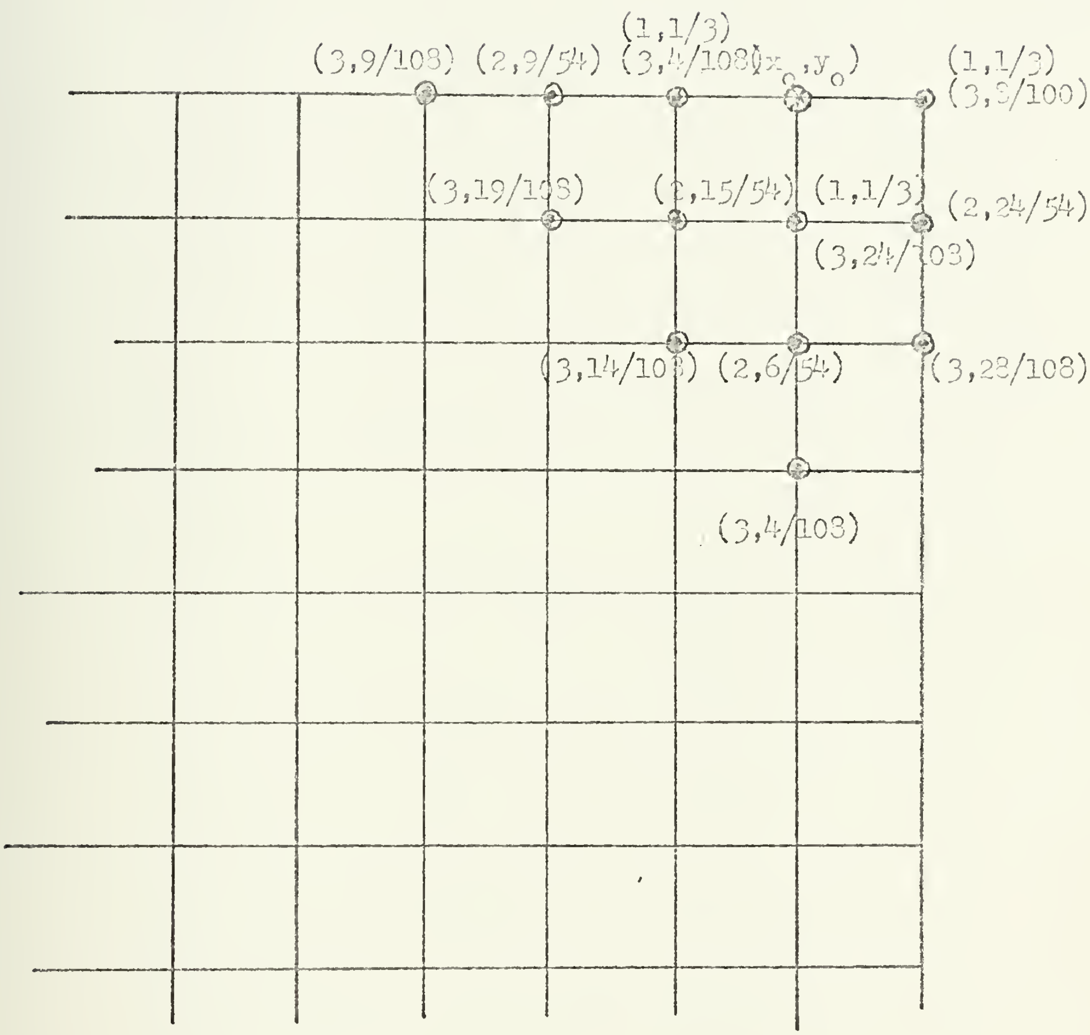
For irregular street designs it would be necessary to create system states at regular intervals such that every intersection could be reached from (x_o, y_o) in an integer multiple of the state interval. While the number of states can become quite large, it is still only

FIGURE 24: RANDOM WALK MODEL



KEY: (i,p) indicates time interval (step) i,
and probability p of being at that location.

FIGURE 25: RANDOM WALK WITH BOUNDARY CONDITIONS



KEY: (i,p) indicates step i, and probability p of being at that intersection.

necessary to append turn probabilities at each intersection to the geographic base file in order to have all the data needed for using this class of location models.

APPENDIX 4

COMPUTER PROGRAM

```
      DIMENSION NH(35),NQ1(3),NQ2(3),NCNT(3),LQ(3,2200),TF(9),
     CT(9),M(36,9),L(9),BUSY(9),NS(3),NUS(3),TQU(9),LQU(9),PQU(9),
     CNPR(9),TT1(36,18),WTTL(3),MXWT(3),MXWTAD(3),NWT(3),LMT(3),HOME(9),
     CAVWT(3),UTIL(9),INTER(3),INTPCT(3),LAMBDA(3),B(9),DTCALL(8),
     CDLCALL(8),DP(8),R(1),NTF(9),RNS(3),RNUS(3),RWTTL(3),RINTER(3)
     C,RBUSY(9),FNEG(125),TQ(3,2200)
      REAL INTPCT, LAMBDA,K1,K2
      INTEGER HOME,BGNSFT,ENDSFT,B,T,PTRUE,WTTL,TF,M,TNOW,TOUR,TT1,P,
     CBUSY,TQU,LQU,PQU,TCALL,LCALL,TEVNT,TEF,TMAX,DTCALL,DLCALL,DP,Z,W
      DO 700 M1=1, 18
700   READ (5,710) (TT1(M1,M2),M2=1,M1)
710   FORMAT(18I2)
      DO 720 M1=19,36
      M3=37-M1
720   READ (5,710) (TT1(M1,M2),M2=1,M3)
740   READ(5,711) ((M(M1,M2),M2=1,9),M1=1,36)
711   FORMAT(9I2)
      READ(5,713) (FNEG(M1),M1=1,125)
713   FORMAT(15F5.3)
      TAU=15.
      DO 9800 JJJJ=1,2
      PROB=.4
      IF (JJJJ.EQ.2) TAU=30.
      DO 3500 JJJ=1,2
      PROB=PROB+.1
3080  REWIND 10
      ASSIGN 170 TO I22
      IF((JJJ+JJJJ).LT.4) GO TO 3011
      ASSIGN 120 TO I22
3011  NATOM=4
      DO 9000 JJ=1,10
3010  READ(10,745) (DTCALL(J),DLCALL(J),DP(J),J=1,8)
745   FORMAT(8(I5,I3,I2))
      I=0
      N=9
      K1=1.
```

```
      K=2
      ESERVT=20.
      KT=30
      KDEV=240
      NADS=0
      TNOW=0
      TOUR=1
      BGNSFT=10
      ENDSFT=20
      LMT(1)=1
      LMT(2)=5
      LMT(3)=20
      ITAU=TAU
      NH(1)=0
      TMAX=120
      K2=1.2
      M9=75
      HOME(1)=1
      HOME(2)=5
      HOME(3)=9
      HOME(4)=13
      HOME(5)=17
      HOME(6)=21
      HOME(7)=25
      HOME(8)=29
      HOME(9)=33
C     LOAD DATA INTO ARRAYS
      DO 6 NN=1,N
      B(NN)=0
      TF(NN)=BGNSFT
      BUSY(NN)=0
      NPP(NN)=0
      L(NN)=HOME(NN)
      T(NN)=TMAX+1
6     TQU(NN)=0
      DO 7 P=1,3
```

```
      NQ1(P)=NQ2(P)=0
      NS(P)=WTTL(P)=NWI(P)=INTER(P)=0
7     MXWT(P)=MXWTAD(P)=0
8     ASSIGN 77 TO Z
      GO TO 600
77    IF(TCALL.GT.(480*(TOUR-1)+BGNSFT)) GO TO 10
      IF(P.GT.1) GO TO 177
      DO 1771 N5=1,N
1771  T(N5)=T(N5)+TCALL-TNOW
      TNOW=TCALL
      IF(NFREE.EQ.0) GO TO 177
      LOC=LCALL
      TEVNT=TCALL
      ASSIGN 600 TO W
      ASSIGN 77 TO Z
      GO TO 900
177   NQ2(P)=NQ2(P)+1
      TQ(P,NQ2(P))=TCALL
      LQ(P,NQ2(P))=LCALL
      GO TO 8
C     MAKE INITIAL ASSIGNMENTS
10    NFREE=N-NH(TOUR)
      IF(TOUR.EQ.1) GO TO 1001
      DO 1000 NN=1,N
      IF(TF(NN).GT.((TOUR-1)*480+BGNSFT)) GO TO 1000
      IF(TF(NN).LE.((TOUR-1)*480)) GO TO 1000
C   CAR FREE BETWEEN SFT AND SFT + BGNSFT
      T(NN)=TMAX+1
      B(NN)=0
      NFREE=NFREE+1
1000  CONTINUE
1001  TNOW=480*(TOUR-1)+BGNSFT
      NK=0
      DO 20 P=1,3
      NCNT(P)=NQ1(P)
      IF(P.GT.1) NK=K
```

```
      IF(NQ1(P).EQ.NQ2(P)) GO TO 20
      N1=NQ1(P)+1
      N71=NQ2(P)
      DO 14 NP=N1,N71
      IF(NFREE.LE.NK) GO TO 20
      LOC=LQ(P,NP)
      TEVNT=TQ(P,NP)
      DO 1500 N5=1,N
      NCAR=M(LOC,N5)
      IF(T(NCAR).LT.TMAX) GO TO 1500
      IF((L(NCAR)+LOC).GT.37) GO TO 1490
      J2=MIN0(L(NCAR),LOC)
      I2=MAX0(L(NCAR),LOC)
      TT=TT1(I2,J2)
      GO TO 1495
1490  I2=MAX0((37-L(NCAR)),(37-LOC))
      J2=MIN0((37-L(NCAR)),(37-LOC))
      TT=TT1(I2,J2)
1495  T(NCAR)=-TT
      L(NCAR)=LOC
1496  CALL RANDS(M9,R,1)
      DO 6010 KSTEP=1,121
      IF(FNEG(KSTEP).GT.R(1)) GO TO 6010
      KTIME=KSTEP-1
      GO TO 1497
6010  CONTINUE
1497  TF(NCAR)=TNOW+KTIME
      NFREE=NFREE-1
      NS(P)=NS(P)+1
      WTTL(P)=WTTL(P)+TNOW-TEVNT
      B(NCAR)=1
      BUSY(NCAR)=BUSY(NCAR)+TF(NCAR)-TNOW
      MXWT(P)=MAX0(MXWT(P),(TNOW-TEVNT))
      IF((TNOW-TEVNT).GT.LMT(P)) NWT(P)=NWT(P)+1
      IF(N5.GT.1) INTER(P)=INTER(P)+1
      GO TO 14
```

```
1500  CONTINUE
14    NCNT(P)=NCNT(P)+1
20    NO1(P)=NCNT(P)
C     TIME ROUTINE
C      FIND ANY UNIT NOT PREVIOUSLY FREE
40    P=PTRUE
      DO 45 N2=1,N
      IF(B(N2).EQ.0) GO TO 45
      TEF=TF(N2)
      GO TO 60
45    CONTINUE
C       ALL UNITS PREVIOUSLY KNOWN TO BE FREE
      TEF=TCALL
50    IF((480*TOUR-MIN0(TEF,TCALL)).LT.ENDSFT) GO TO 80
      IF(MIN0(TEF,TCALL).LT.KDEV) GO TO 9999
      ASSIGN 9999 TO I2G
      GO TO 300
9999  IF(TCALL-TEF) 100,100,210
C      AT LEAST ONE UNIT HAS NOT ALREADY BEEN HANDLED
60    DO 70 N2=1,N
      IF(B(N2).EQ.0) GO TO 70
      IF(TF(N2).GT.TEF)  GO TO 70
      TEF=TF(N2)
      NUNIT=N2
70    CONTINUE
      GO TO 50
C     HOLD ROUTINE FOR END OF TOURS
80    NH(TOUR+1)=0
      NOTL=MIN0(TCALL,TEF)
      DO 81 NN=1,N
      NTF(NN)=TF(NN)
      IF(TQU(NN).EQ.0) GO TO 81
C      CAR NN STILL ON CALL WITH ADS QUEUE
85    CALL RANDS(M9,R,1)
      DO 7010 KSTEP=1,121
      IF(FNEG(KSTEP).GT.R(1)) GO TO 7010
```

```
      KTIME=KSTEP-1
      GO TO 889
7010  CONTINUE
889   IF(TOUR.EQ.KT) GO TO 888
      IF((L(NN)+LQU(NN)).GT.37) GO TO 1216
      I2=MAX0(L(NN),LQU(NN))
      J2=MIN0(L(NN),LQU(NN))
      TT=TT1(I2,J2)
      GO TO 1218
1216  I2=MAX0((37-L(NN)),(37-LQU(NN)))
      J2=MIN0((37-L(NN)),(37-LQU(NN)))
      TT=TT1(I2,J2)
1218  T(NN)=-TT+NOTL-TF(NN)+480*TOUR+BGNSFT
      L(NN)=LQU(NN)
      NS(PQU(NN))=NS(PQU(NN))+1
      WTTL(PQU(NN))=WTTL(PQU(NN))+TF(NN)-TQU(NN)
      MXWTAD(PQU(NN))=MAX0(MXWTAD(PQU(NN)),(TF(NN)-TQU(NN)))
      IF((TF(NN)-TQU(NN)).GT.LMT(PQU(NN))) NWT(PQU(NN))=NWT(PQU(NN))+1
      TQU(NN)=0
888   TF(NN)=TF(NN)+KTIME
81    CONTINUE
      DO 82 NN=1,N
      IF(TF(NN).GT.(480*TOUR)) GO TO 83
      B(NN)=0
      T(NN)=TMAX+1
      L(NN)=HOME(NN)
      GO TO 82
83    NH(TOUR+1)=NH(TOUR+1)+1
82    CONTINUE
      ASSIGN 95 TO I2G
88    IF(TCALL.GT.KDEV) GO TO 300
C     QUEUE CALLS TILL BGNSFT NEXT,TOUR
      IF(P.GT.1) GO TO 188
      DO 1105 N5=1,N
1105  T(N5)=T(N5)+TCALL-TNOW
      TNOW=TCALL
```

```
      IF(NFREE.EQ.0) GO TO 188
      LOC=LCALL
      TEVNT=TCALL
      ASSIGN 600 TO W
      ASSIGN 88 TO Z
      GO TO 900
188   NQ2(P)=NQ2(P)+1
      TQ(P,NQ2(P))=TCALL
      LQ(P,NQ2(P))=LCALL
      ASSIGN 88 TO Z
      GO TO 600
95    TOUR=TOUR+1
      GO TO 77
C       NEW CALL FIRST ROUTINE
100   DO 105 N5=1,N
105   T(N5)=T(N5)+TCALL-TNOW
      TNOW=TCALL
      IF(P.GT.1) GO TO 150
      IF(NFREE.GT.0) GO TO 120
      NQ2(1)=NQ2(1)+1
      TQ(1,NQ2(1))=TCALL
      LQ(1,NQ2(1))=LCALL
      ASSIGN 40 TO Z
      GO TO 600
8818  GO TO I22,(120,170)
C     SERVE PRI 1 CALL, OR ADS FAILURE
120   LOC=LCALL
      TEVNT=TCALL
      ASSIGN 600 TO W
      ASSIGN 40 TO Z
      GO TO 900
150   IF(NFREE.LE.K) GO TO 200
      IF((480*TOUR-TCALL).LT.(K1*ESERVT)) GO TO 200
C       IF NFREE IS GT K NO QUEUES EXIST
      LOC=LCALL
      NUNIT=M(LOC,1)
```

```
9850  IF(T(NUNIT).LE.TMAX) GO TO 8818
C     SECTOR UNIT FREE
9860  IF((L(NUNIT)+LOC).GT.37) GO TO 152
      J2=MINO(L(NUNIT),LOC)
      I2=MAXO(L(NUNIT),LOC)
      TT=TT1(I2,J2)
      GO TO 154
152   I2=MAXO((37-L(NUNIT)),(37-LOC))
      J2=MINO((37-L(NUNIT)),(37-LOC))
      TT=TT1(I2,J2)
154   T(NUNIT)=-TT
155   ASSIGN 156 TO JUMP
      GO TO 8000
156   TF(NUNIT)=TNOW+KTIME
      NFREE=NFREE-1
      B(NUNIT)=1
      NS(P)=NS(P)+1
      BUSY(NUNIT)=BUSY(NUNIT)+TF(NUNIT)-TNOW
      ASSIGN 40 TO Z
      GO TO 600
C    ADS PROBABLITY ROUTINE
170   IF(TQU(NUNIT)) 120,175,120
175   IF(T(NUNIT).LT.0) GO TO 120
      IF((480*TOUR-TCALL).LT.(K2*(TAU+ESERVT))) GO TO 120
      NADS=NADS+1
      IF(T(NUNIT).GE.(TMAX-ITAU)) GO TO 180
      FN=(FNEG(T(NUNIT)+1)-FNEG(T(NUNIT)+ITAU+1))/FNEG(T(NUNIT)+1)
      IF(FN.LT.PROB) GO TO 120
180   TQU(NUNIT)=TCALL
      LQU(NUNIT)=LCALL
      PQU(NUNIT)=P
      NPR(NUNIT)=NPR(NUNIT)+1
      ASSIGN 40 TO Z
      GO TO 600
C     NOT ENUF UNITS OR TIME, QUEUE CALL
200   NQ2(P)=NQ2(P)+1
```

```
      TQ(P,NQ2(P))=TCALL
      LQ(P,NQ2(P))=LCALL
      ASSIGN 40 TO Z
      GO TO 600
C     FREE CAR FIRST ROUTINE
210   B(NUNIT)=0
      NFREE=NFREE+1
      DO 214 N5=1,N
214   T(N5)=T(N5)+TEF-TNOW
      T(NUNIT)=TMAX+1
C    FREE CAR WILL HAVE T GT TMAX, TEF=TF,TNOW=TCALL LAST
      TNOW=TEF
      IF (TQU(NUNIT).EQ.0) GO TO 220
C     ADS QUEUE, UNIT'S OWN SECTOR
      IF(NQ1(1).LT.NQ2(1)) GO TO 2225
      IF((L(NUNIT)+LQU(NUNIT)).GT.37) GO TO 216
      J2=MINO(L(NUNIT),LQU(NUNIT))
      I2=MAXO(L(NUNIT),LQU(NUNIT))
      TT=TT1(I2,J2)
      GO TO 218
216   I2=MAXO((37-L(NUNIT)),(37-LQU(NUNIT)))
      J2=MINO((37-L(NUNIT)),(37-LQU(NUNIT)))
      TT=TT1(I2,J2)
218   T(NUNIT)=-TT
      L(NUNIT)=LQU(NUNIT)
      NFREE=NFREE-1
219   ASSIGN 221 TO JUMP
      GO TO 8000
221   TF(NUNIT)=TNOW+KTIME
      B(NUNIT)=1
      NS(PQU(NUNIT))=NS(PQU(NUNIT))+1
      WTTL(PQU(NUNIT))=WTTL(PQU(NUNIT))+TNOW-TQU(NUNIT)
      BUSY(NUNIT)=BUSY(NUNIT)+TF(NUNIT)-TNOW
      MXWTAD(PQU(NUNIT))=MAXO(MXWTAD(PQU(NUNIT)),(TNOW-TQU(NUNIT)))
      IF((TNOW-TQU(NUNIT)).GT.LMT(PQU(NUNIT))) NWT(PQU(NUNIT))=NWT(PQU(
     CNUNIT))+1
```

```
      TQU(NUNIT)=0
      GO TO 40
C    NO ADS QUEUE
220   IF(NQ1(1).EQ.NQ2(1)) GO TO 2220
2225  NQ1(1)=NQ1(1)+1
      LOC=LQ(1,NQ1(1))
      P=1
      TEVNT=TQ(1,NQ1(1))
      ASSIGN 40 TO W
      GO TO 900
2220  IF((480*TOUR-TEF).GE.(K1*ESERVT)) GO TO 240
      L(NUNIT)=HOME(NUNIT)
      GO TO 40
C     SERVE FIRST CALL IN HIGHEST PRIORITY QUEUE
C     ARE THERE ENUF FREE UNITS?
240   IF(NFREE.LE.K) GO TO 40
      ASSIGN 2498 TO JUMP
      GO TO 8000
2498  DO 250 P=2,3
      IF(NQ1(P).EQ.NQ2(P)) GO TO 250
      NQ1(P)=NQ1(P)+1
      LOC=LQ(P,NQ1(P))
      TEVNT=TQ(P,NQ1(P))
      DO 2500 N5=1,N
      NCAR=M(LOC,N5)
      IF(T(NCAR).LT.TMAX) GO TO 2500
      IF((L(NCAR)+LOC).GT.37) GO TO 2490
      J2=MIN0(L(NCAR),LOC)
      I2=MAX0(L(NCAR),LOC)
      TT=TT1(I2,J2)
      GO TO 2495
2490  I2=MAX0((37-L(NCAR)),(37-LOC))
      J2=MIN0((37-L(NCAR)),(37-LOC))
      TT=TT1(I2,J2)
2495  T(NCAR)=-TT
      L(NCAR)=LOC
```

```
2497  TF(NCAR)=TNOW+KTIME
      NFREE=NFREE-1
      B(NCAR)=1
      NS(P)=NS(P)+1
      WTTL(P)=WTTL(P)+TNOW-TEVNT
      BUSY(NCAR)=BUSY(NCAR)+TF(NCAR)-TNOW
      MXWT(P)=MAX0(MXWT(P),(TNOW-TEVNT))
      IF((TNOW-TEVNT).GT.LMT(P)) NWT(P)=NWT(P)+1
      IF(N5.GT.1) INTER(P)=INTER(P)+1
      GO TO 245
2500  CONTINUE
245   IF(.NOT.(NCAR.EQ.NUNIT)) L(NUNIT)=HOME(NUNIT)
C    OTHER CAR DISPATCHED
      GO TO 40
250   CONTINUE
C    NO QUEUED CALLS
      L(NUNIT)=HOME(NUNIT)
      GO TO 40
C    FETCH NEXT CALL
600   I=I+1
      IF(I.LE.8) GO TO 620
      READ(10,610) (DTCALL(J),DLCALL(J),DP(J),J=1,8)
610   FORMAT(8(I5,I3,I2))
      I=1
620   TCALL=DTCALL(I)
      LCALL=DLCALL(I)
      P=DP(I)
      PTRUE=P
      GO TO Z,(77,88,40)
C    SERVE CALL
900   ASSIGN 498 TO JUMP
      GO TO 8000
498   DO 500 N5=1,N
      NCAR=M(LOC,N5)
      IF(T(NCAR).LT.TMAX) GO TO 500
      IF((L(NCAR)+LOC).GT.37) GO TO 490
```

```
      J2=MINO(L(NCAR),LOC)
      I2=MAXO(L(NCAR),LOC)
      TT=TT1(I2,J2)
      GO TO 495
490   I2=MAXO((37-L(NCAR)),(37-LOC))
      J2=MINO((37-L(NCAR)),(37-LOC))
      TT=TT1(I2,J2)
495   T(NCAR)=-TT
      L(NCAR)=LOC
497   TF(NCAR)=TNOW+KTIME
      NFREE=NFREE-1
      NS(P)=NS(P)+1
      WTTL(P)=WTTL(P)+TNOW-TEVNT
      B(NCAR)=1
      BUSY(NCAR)=BUSY(NCAR)+TF(NCAR)-TNOW
      MXWT(P)=MAXO(MXWT(P),(TNOW-TEVNT))
      IF((TNOW-TEVNT).GT.LMT(P)) NWT(P)=NWT(P)+1
      IF(N5.GT.1) INTER(P)=INTER(P)+1
      GO TO 520
500   CONTINUE
520   GO TO W,(600,40)
8000  CALL RANDS(M9,R,1)
      DO 8010 KSTEP=1,121
      IF(FNEG(KSTEP).GT.R(1)) GO TO 8010
      KTIME=KSTEP-1
      GO TO 8020
8010  CONTINUE
8020  GO TO JUMP,(156,221,2498,498)
C       STATISTICS PACKAGE
300   DO 3310 P=1,3
      IF(NQ1(P).EQ.NQ2(P)) GO TO 3310
      IH1=NQ1(P)+1
      IH2=NQ2(P)
      DO 3320 IH=IH1,IH2
      WTTL(P)=WTTL(P)+(480*KT-TQ(P,IH))
3320  CONTINUE
```

```
3310  CONTINUE
      DO 310 P=1,3
      AVWT(P)=0
      INTPCT(P)=0
305   NUS(P)=NQ2(P)-NQ1(P)
      RNUS(P)=NUS(P)
      RNS(P)=NS(P)
      R8=8*KT
      IF(NS(P).EQ.0) GO TO 3330
      RINTER(P)=INTER(P)
      INTPCT(P)=RINTER(P)/RNS(P)
3330  IF((NS(P)+NUS(P)).EQ.0) GO TO 310
      RWTTL(P)=WTTL(P)
      AVWT(P)=RWTTL(P)/(RNUS(P)+RNS(P))
310   LAMBDA(P)=(RNS(P)+RNUS(P))/R8
      TBUSY=0
      DO 320 NN=1,N
      RBUSY(NN)=BUSY(NN)
      TBUSY=TBUSY+RBUSY(NN)
      RKT=480*KT
320   UTIL(NN)=RBUSY(NN)/RKT
      AVUTL=TBUSY/(RKT*9.)
C     BUSY TIME EXCLUDES BGNSFT AND ENDSFT
C      OUTPUT ROUTINE
      WRITE(6,401)
401   FORMAT('1','ADAPTIVE DISPATCH SIMULATION')
      WRITE(6,400) N
400   FORMAT ('0','NUMBER OF UNITS=',1X,I3)
      WRITE(6,405) K
405   FORMAT(' ','NUMBER OF RESERVE UNITS =',1X,I3)
      WRITE(6,410) KT
410   FORMAT(' ','NUMBER OF TOURS =',1X,I3)
      WRITE(6,415) NATOM
415   FORMAT(' ','NUMBER OF ATOMS PER SECTOR =',1X,I3)
      WRITE(6,420) PROB, TAU
420   FORMAT(' ','ADAPTIVE DISPATCH PARAMETERS:',3X,'CONFIDENCE LEVEL ='
```

```
     C,1X,F4.2,5X,'TIME ALLOWANCE =',1X,F4.1,2X,'MINUTES')
      WRITE(6,422)
422   FORMAT('0','STATISTIC',15X,'PRIORITY 1',5X,'PRIORITY 2',5X,
     C'PRIORITY 3')
      WRITE(6,425) (LAMBDA(P),P=1,3)
425   FORMAT('0','ARRIVAL RATE',F21.6,2F15.6)
4444  WRITE(6,430) (NS(P),P=1,3)
430   FORMAT(' ','CALLS SERVICED',I19,2I15)
      WRITE(6,435) (NUS(P),P=1,3)
435   FORMAT(' ','CALLS NOT SERVICED',I15,2I15)
      WRITE(6,440) (AVWT(P),P=1,3)
440   FORMAT(' ','AVERAGE WAIT',F21.6,2F15.6)
      WRITE(6,445) (MXWT(P),P=1,3)
445   FORMAT(' ','MAXIMUM WAIT',I21,2I15)
      WRITE(6,450) (MXWTAD(P),P=1,3)
450   FORMAT(' ','MAX ADS WAIT',I21,2I15)
      WRITE(6,455) (NWT(P),P=1,3)
455   FORMAT(' ','EXCESS WAIT CALLS',I16,2I15)
      WRITE(6,460) (INTPCT(P),P=1,3)
460   FORMAT(' ','INTERSECTOR DISPATCH',F13.6,2F15.6)
      WRITE(6,462)
462   FORMAT('0','CAR NUMBER',15X,'UTILIZATION',5X,'ADS DISPATCHES',
     C5X,'LAST FREE',5X,'QUEUED CALL TIME')
      WRITE(6,465) (N7,UTIL(N7),NPR(N7),NTF(N7),TQU(N7),N7=1,9)
465   FORMAT('0',I7,F25.6,I18,I15,I18)
5555  WRITE(6,475) AVUTL
475   FORMAT('0','AVERAGE UTILIZATION =',F10.5)
9000  CONTINUE
3500  CONTINUE
9800  CONTINUE
9998  STOP
      END
$ENTRY
 0
 1 0
 1 1 0
```

1 1 1 0
2 1 2 1 0
3 2 3 2 1 0
2 1 2 1 1 1 0
3 2 3 2 1 1 1 0
2 2 1 1 2 3 2 3 0
2 2 1 1 2 2 1 2 1 0
3 3 2 2 3 3 2 3 1 1 0
3 3 2 2 3 3 2 2 1 1 1 0
4 3 4 3 2 1 2 1 4 3 4 3 0
5 4 5 4 3 2 3 2 5 4 5 4 1 0
4 3 4 3 2 1 2 1 4 3 4 3 1 1 0
5 4 5 4 3 2 3 2 5 4 5 4 1 1 1 0
2 2 2 1 2 2 1 1 2 1 2 1 2 3 2 3 0
3 2 3 2 2 2 1 1 3 2 3 2 2 2 1 2 1 0
3 3 2 2 3 3 2 2 2 1 2 1 3 3 2 3 1 1
3 3 3 2 3 3 2 2 3 2 3 2 3 3 2 2 1
4 4 3 3 4 4 3 3 2 2 1 1 4 5 4 5
4 4 3 3 4 4 3 3 2 2 1 1 4 4 3
5 5 4 4 5 5 4 4 3 3 2 2 5 5
5 5 4 4 5 5 4 4 3 3 2 2 5
4 3 4 3 2 2 2 1 4 3 4 3
5 4 5 4 3 2 3 2 5 4 5
4 3 4 3 3 3 2 2 4 3
5 4 5 4 3 3 3 2 5
4 4 3 3 4 4 3 3
4 4 3 3 4 4 3
5 5 4 4 5 5
5 5 4 4 5
4 4 4 3
5 4 5
5 5
5
1 2 3 5 4 6 7 8 9
1 2 3 5 4 7 6 8 9
1 3 2 5 6 4 8 7 9

1	2	3	5	4	6	7	8	9
2	1	4	3	5	7	6	8	9
2	4	1	7	3	5	6	8	9
2	1	3	5	4	7	6	8	9
2	4	5	7	1	3	6	8	9
3	1	2	6	5	8	4	7	9
3	1	2	5	6	8	4	7	9
3	6	1	2	8	5	4	7	9
3	6	8	5	1	2	4	7	9
4	2	7	5	1	3	9	8	6
4	2	7	5	1	3	8	9	6
4	2	7	5	1	3	8	9	6
4	7	2	5	9	8	1	3	6
5	2	3	1	4	6	7	8	9
5	4	2	7	1	9	3	8	6
5	6	3	8	9	1	7	2	4
5	7	9	8	4	6	3	2	1
6	3	8	5	1	2	9	7	4
6	8	3	5	9	7	2	1	4
6	8	3	5	9	7	2	1	4
6	8	3	5	9	7	1	2	4
7	4	2	5	9	8	6	3	1
7	4	9	8	5	2	6	3	1
7	9	8	5	4	2	6	3	1
7	9	8	4	5	2	6	3	1
8	6	3	5	9	7	4	2	1
8	9	7	5	6	3	4	2	1
8	6	9	7	5	3	4	2	1
8	9	6	7	3	5	4	2	1
9	7	8	5	4	6	2	3	1
9	7	8	5	4	2	6	3	1
9	8	7	5	6	3	4	2	1
9	8	7	5	6	4	3	2	1

1.000	.970	.910	.850	.820	.790	.745	.700	.660	.630	.580	.550	.530	.500	.475
.450	.430	.415	.400	.380	.350	.340	.330	.320	.310	.300	.285	.270	.260	.250
.240	.230	.220	.210	.205	.200	.190	.180	.175	.170	.165	.160	.155	.150	.145